THE MUSEUM OF SCIENCE & ART

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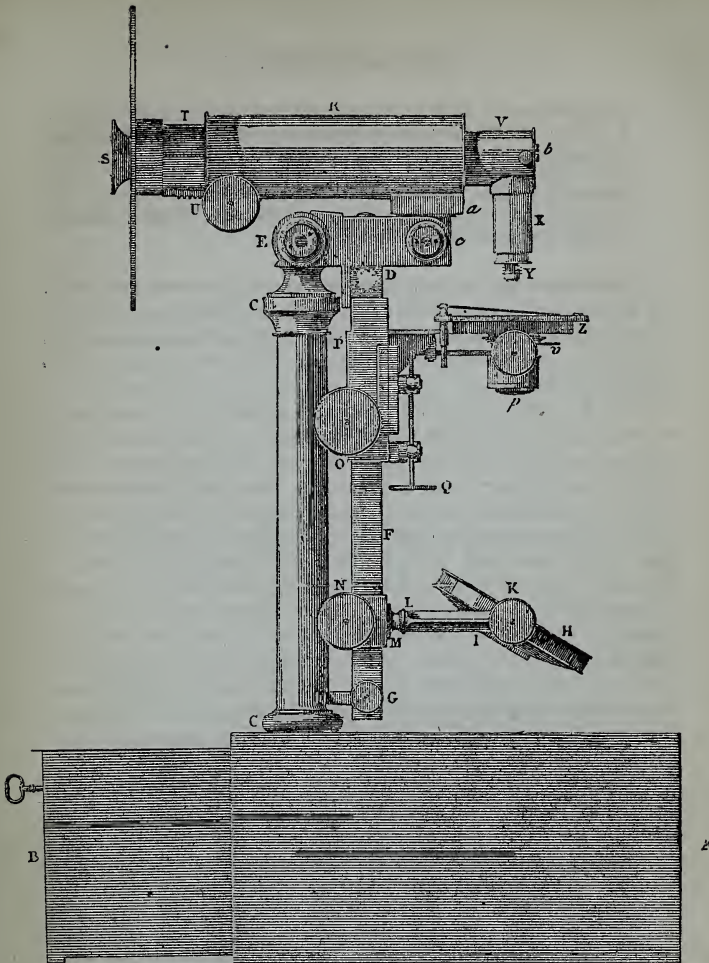


Fig. 37.—CHEVALIER'S UNIVERSAL MICROSCOPE.

THE MICROSCOPE.

CHAPTER I.

1. Origin of the term.—2. Simple microscopes are magnifying glasses.—3. Compound microscope.—4. Object-glass and eye-glass.—5. General description of the instrument.—6. Uses of the field-glass.—7. Reflect-

ing microscopes.—8. Conditions of distinct vision in the microscope.—9. Effects of different magnifying powers.—10. Distinctness of delineation necessary.—11. Hence aberration must be effaced.—12. Achromatic object-lenses.—13. Sufficient illumination necessary.—14. Effects of angular aperture.—15. Experiments of Dr. Goring.—16. Method of determining the angular aperture.—17. Mutual chromatic and spherical correction of the lenses.

1. The microscope is an optical instrument by means of which we are enabled to see objects or the parts of objects too minute to be seen distinctly with the naked eye, the name being taken from two Greek words, μικρὸν (mikron), *a little thing*, and σκοπέω (skopeo), *I look at.*

2. In a certain sense, all magnifying-glasses may be regarded as microscopes, but the slightly convex lenses, used by weak-sighted persons, cannot with any propriety be so denominated. The higher magnifying lenses, however, used by watchmakers, jewellers, miniature painters, and others, may with less impropriety receive the name; and the small lenses of short focus and high power described in our Tract on "Magnifying Glasses," especially when they have the form of doublets, and are mounted to serve anatomical purposes, and for microscopic delineations, are generally designated *simple microscopes.* Since, however, they differ in no respect in their optical principle from common magnifiers, we have considered it more convenient to explain them under that head, limiting therefore the subject of the present Tract to those optical combinations which are generally called COMPOUND MICROSCOPES.

3. Such an instrument, in its most simple form, consists of a magnifying lens or combination of lenses, by means of which an enlarged optical image of a minute object is produced, and a magnifying lens, or combination of lenses, by which such image is viewed, as an object would be by a simple microscope.

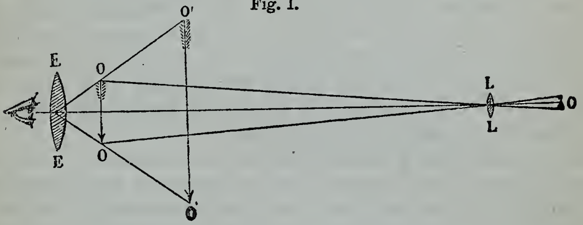
4. The former is called the OBJECT-GLASS, or OBJECTIVE, since it is always directed immediately to the object, which is placed very near to it; and the latter the EYE-GLASS, or EYE-PIECE, inasmuch as the eye of the observer is applied to it, to view the magnified image of the object.

5. Such a combination will be more clearly understood by reference to fig. 1, where *o* is the object, L L the object-glass, and E E the eye-glass.

The object-glass, L L, is a lens of very short focal length, and the object *o* is placed in its axis, a very little beyond its focus. According to what has been explained in our Tract upon "Optical Images," 31 *et seq.* an image O O, of *o*, will be produced at a distance from the object-glass L L, much greater than the distance of *o* from it: this image will be inverted with relation to the object; its top corresponding with the bottom, and its right with the left side of the object, and *vice versâ:* the linear magnitude of this image will be greater than that of the object, in the proportion of O L to *o* L, and consequently its superficial magnitude will be greater than that of the object, in the proportion of the squares of these lines.

The image O O, thus formed, may be considered as an object viewed by the observer, through the magnifying glass E E, and all that has been explained, relating to the effect of such a lens, in our Tracts on "Magnifying Glasses" and "Optical Images," will be applicable in this case. The observer will adjust the eye-glass

Fig. 1.



E E, at such a distance from O O, as will enable him to see the image most distinctly, and the impression produced upon his sense of vision will be that the image he looks at, is at that distance from his eye, at which he would see such an object most distinctly without the interposition of any magnifying lens; let this distance be that of a similar image O′ O′, and the impression will be that the object he beholds has the magnitude O′ O′.

The distance of most distinct vision with the naked eye, and the distance from the image at which the eye-glass must be placed to produce distinct vision, both vary for different eyes, but they vary almost exactly in the same proportion, so that the magnifying effect of the eye-glass upon the image O O, will be the same, whether the observer be long-sighted or short-sighted; in estimating the magnifying power, therefore, of such a combination, we may consider, in all cases, the distance of the eye-glass E E from the image O O, to be equal to its focal length, and the distance of O′ O′ from the eye-glass, to be 10 inches. (See "Magnifying Glasses," 8.)

To estimate the entire amplifying effect of such a microscope, we have only to multiply the magnifying power of the object-glass by that of the eye-glass; thus, for example, if the distance of the image O O from the object-glass be 10 times as great as the distance of the object from it, the linear dimensions of the image O O will be 10 times greater than those of the object; and if the focal length of the eye-glass be $\frac{1}{2}$ an inch, the distance of most distinct vision being 10 inches, the linear dimensions of O′ O′ will be 20 times those of O O, and therefore 200 times those of the object; the linear magnifying power would in that case be 200, and consequently the superficial magnifying power 40000.

It would seem therefore, theoretically, that there would be no limit to the magnifying power of such a combination; practically, however, there are circumstances which do impose a limit upon it. It must be remembered that the object must always be placed at a distance from the object-glass, greater than the focal length of the latter, the magnifying power of the object-glass depending on the number of times this distance is multiplied, to make up the distance of the image O O from L L; if a very great magnifying power be required, the latter distance must be a proportionally great multiple of the former, and as the eye-glass must be farther from the object-glass than the image, the instrument might be increased to unmanageable dimensions.

There is therefore a practical limit to the increase of the amplifying power of the instrument by the increase of the distance of the image O O from the object-glass, and consequently it can only be augmented by the decrease of the focal length of the object-glass, combined with a corresponding decrease of that of the eye-glass. By such means, the distance of *o* from L L will be contained a great number of times in O L, while the latter has not objectionable length, and the distance of the eye-glass from the image O O will be contained a great number of times in the distance of most distinct vision.

The eye and object glasses are usually mounted at the distance of 10 or 12 inches asunder, adjustments nevertheless being provided, by which their mutual distance can be varied within certain limits.

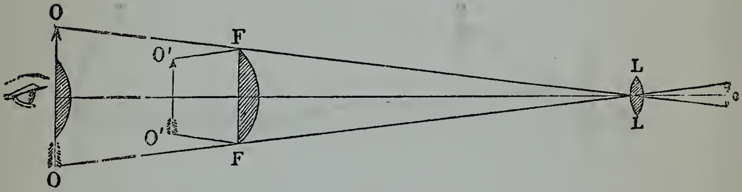
6. A convex lens is generally interposed between the object-glass and eye-glass, which receiving the rays diverging from the former, before they form an image, has the effect of contracting the dimensions of the image, and at the same time increasing its brightness. The effect of such an intermediate lens will be understood by reference to fig. 2, where F F is the intermediate lens. If this lens F F were not interposed, the object-glass L L would form an image of the object *o* at O O; but this image being too large to be seen at once with any eye-glass, a certain portion of its central part would only be visible. The lens F F, however, receiving the rays before they arrive at the image O O, gives them increased convergence, and causes them to produce a smaller

image o′ o′, at a less distance from the object-glass L L. The dimensions of this image are so small, that every part of it can be seen at once with the eye-glass.

The portion of the image which can be seen at once with the eye-glass, is called the FIELD OF VIEW of the microscope.

It is evident from what has been stated, that the effect of the

Fig. 2.



lens F F is to increase the field of view, since by its means the entire image of the object can be seen, while without its interposition the central parts only would be visible.

The lens F F has, from this circumstance, been called the FIELD-LENS.

But the increase of the field is not the only effect of this arrangement.

The light which would have been diffused over the surface of the larger image o o, is now collected upon that of the smaller image o′ o′; and the brightness, therefore, will be increased in the same proportion as the surface of o o is greater than the surface of o′ o′, that is, in the proportion of the square of o o to the square of o′ o′.

Another effect of the field-lens is to diminish the length of the microscope, for the eye-glass, instead of being placed at its focal distance from o o, is now placed at the same distance from o′ o′.

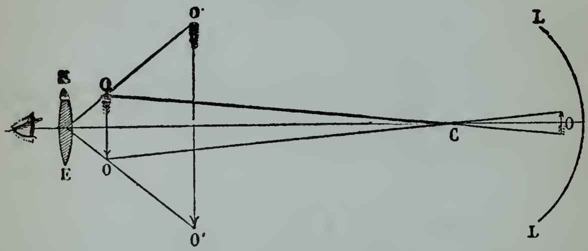
7. In this brief exposition of the general principle of the microscope, the image, which is the immediate subject of observation, is supposed to be produced by a convex lens; such an image, however, may also be produced by a concave reflector, and being so produced may be viewed with an eye-glass, exactly in the same manner as when produced by a convex lens.

Microscopes have accordingly been constructed upon this principle, and are distinguished as REFLECTING MICROSCOPES; those in which the image is produced by a lens being called REFRACTING MICROSCOPES.

The principle of a reflecting microscope will be understood by reference to fig. 3, where L L is the concave reflector, of which C is the centre; the object *o* is placed towards the reflector, at a distance from C greater than half the radius, and an inverted image of it is formed at O O, which, as in the case of the refracting microscope, is looked at with an eye-glass E E.

The great improvements which have taken place within the last twenty years in the formation of the object-glasses of refracting microscopes, have rendered these so very superior to reflecting

Fig. 3.



microscopes, that the latter class of instruments having fallen so completely into disuse, it will not be necessary here to notice them further.

In what has been explained, the general principle only of the microscope has been developed; many important circumstances of detail upon which its efficiency mainly depends must now be noticed.

8. The conditions which render the vision of an object with the microscope clear and distinct are essentially the same as those which determine the clearness and distinctness of our perception of an object with the naked eye. It will be found, by reference to our Tract upon "the Eye," that these conditions are three:—

1. That the visual angle should be sufficiently large;

2. That the outlines and lineaments of the object should be sufficiently distinct; and

3. That the object should be sufficiently illuminated.

It is evident that if any one of these conditions fail to be fulfilled, our visual perception of the object will be defective. If the object, for example, be exceedingly minute, though it be perfectly delineated and strongly illuminated, it will be either altogether invisible, or will appear as a mere speck.

If its outlines and lineaments be ill-defined, as when a tree or other object is seen through a mist, our perception of it will also be defective; and in fine, though it have sufficient magnitude and be perfectly delineated, we may fail to see it distinctly for want of sufficient light upon it, as when we look at objects towards the close of twilight.

The object which is submitted to our sense of vision with the microscope, being the optical image produced by the object-glass, our perception of it can only be clear and distinct, provided the three conditions above stated are fulfilled, that is, provided it be viewed under a sufficient visual angle, that its outline and lineaments be shown with perfect distinctness, and that it be sufficiently illuminated.

The conditions, therefore, upon which the efficiency of the microscope must depend will necessarily be those which will confer upon the image, submitted to the observer, the qualities above stated.

The optical conditions which determine the visual angle or apparent magnitude of the image, as viewed with the eye-glass, have been already explained; and it is evident that these conditions can always be fulfilled, provided object-glasses and eye-glasses of sufficiently short focus can be produced. Speaking generally, the magnifying power of the object-glass will be limited by the proportion which the length of the microscope will bear to its focal length; and the magnifying power of the eye-glass will be limited only by its power of approaching sufficiently close to the image, without too much contracting the field of view.

If the purpose of the observer were merely to see the object as a whole, so as to obtain a perfectly accurate notion of its outlines, a moderate magnifying power would, in general, suffice. But in most microscopic researches it is desired to ascertain, not merely the general outlines of the object, but the far more minute lineaments of its structure; and to render these visible in the minuter class of objects, amplifying powers of a very high order are indispensable.

9. The powers, indeed, which exhibit to the observer the general outline of an object, are rarely sufficient to show the minute lineaments of its structure. To perceive the general outline, it is necessary that the entire object should be included at once within the field of view, and this could not be the case, if the magnifying power exceeded a moderate limit. The power, on the other hand, which is sufficiently great to show the most minute parts of the structure, would necessarily be so great that a very small part only of the entire object would be comprised in the field of view.

From these circumstances it will be readily understood, that each class of powers have their peculiar uses, neither superseding the other; when we desire to observe the general form of a microscopic object, we must view it with a low power. When we desire, on the other hand, to examine its parts, and if, for example, it be an animalcule, to observe it member by member, and organ by organ, we must call to our aid the higher class of power. In fine, a complete microscopic analysis of an individual object will require that it should be viewed successively with a series of gradually increasing powers.

10. But magnifying powers, to whatever extent they may be carried, will be of no avail if the image produced by the object-glass be not perfectly distinct and well defined; and it will be evident upon the slightest consideration, that any minute imperfections which may exist in its delineation, will be rendered more and more glaring and intolerable, the higher the magnifying power under which it is viewed.

With a common magnifying glass, or simple microscope, we view the object itself, and are subject to no other optical imperfections in our perception of it, than such as may arise from the imperfection of the lenses through which we view it; and since with such instruments the magnifying power can never be considerable, small defects of delineation are never perceptible. It is quite otherwise, however, with the class of instruments now under consideration, where magnifying powers, from 1000 to 2000 of the linear dimensions, are often brought into play.

These circumstances render it indispensable that the image of the object produced by the object-glass, and viewed through the eye-glass, should have the utmost attainable distinctness of delineation; not only as regards its outline, but also as respects the most minute details of its structure and colouring.

11. Now the solution of this problem, presented to scientific and practical men the most enormous difficulties; difficulties so great as to have been regarded, by some of the highest scientific authorities of the last half-century, as absolutely insurmountable. Happily, nevertheless, the problem has been solved; and without disparagement to the great lights of science, we must admit that its solution has been mainly the work of practical opticians. It is true that the general principles upon which the form and material of the lenses depend, were the result of profound mathematical research, but these principles were established and well understood at the moment when the practical solution of the problem was, by scientific authorities themselves, pronounced to be all but impossible. Opticians, stimulated by microscopists and amateurs, then applied themselves to the work, and by a long series of laborious and costly trials, attended with many and most discouraging failures, at length arrived at the production of optical combinations, which have rendered the microscope one of the most perfect instruments of philosophic research, and one, to the increasing powers of which, we can scarcely see how any limit can be assigned.

To appreciate the circumstances in which these great difficulties have consisted, it will be necessary that the reader should revert to our Tract upon "Optical Images," 39 *et seq.* It is there shown, that when an object is placed before a convex lens, the image of it which is produced, is not in any case a faithful copy of the object. In the first place, each portion of the lens, proceeding from its centre to its borders, produces a separate image; this series of images, being ranged at different distances from the lens: when these images are looked at, as they would be, for example, with the eye-glass of the microscope, they are seen projected one upon another, and being slightly different in their magnitudes, a confusion of outline and lineaments ensues, so that the object appears as though it were viewed through a mist.

This sort of indistinctness, called *spherical aberration*, has been fully explained in our Tract upon "Optical Images," and the general principles, by which its effects may be more or less mitigated, have been there explained.

It has been in the diminution, if not entire extinction, of this cause of indistinctness, by the happy adaptation of the curvatures of the lenticular surfaces entering into the optical combinations which form the microscope, that the address and genius of the practical opticians has been chiefly manifested; and if it cannot be stated, with strict truth, that all the effects of spherical aberration have been effaced in the best instruments now placed at the disposition of the observer, it may, at all events, be safely affirmed, that they exist in so small a degree as to offer no serious impediment to his researches.

But independently of this source of indistinctness, there is another which has also been fully explained in our Tract upon "Optical Images," 39.

Light is a compound principle, consisting of several elements, differing in colour and also in refrangibility, the consequence of which is, that when an object is placed before a convex lens, it is not one image which is formed of it, but a series of images, varying in colour, from a violet or blue, through all the tints of the rainbow, to a red; these images are placed at slightly different distances from the lens, and when viewed through the eye-glass, would be projected one upon the other, and being of slightly different magnitudes, the consequence of such projection would be, that their outlines, and those of all their parts, would be more or less fringed with iridescent colours, an effect which, it is needless to say, would destroy the distinctness of the lineaments.

12. The principle upon which this chromatic aberration is counteracted, has been fully explained in our Tract upon "Optical

Images." It follows from what is there stated, that all confusion produced by this cause, can be removed by substituting for simple convex lenses, compound ones, consisting of a double convex lens of crown-glass C C′, fig. 4, cemented to a plano-concave lens of flint glass.

Fig. 4.

The image produced by such a combination, will be distinct and free from colour, provided that certain conditions be observed in the curvatures given to its component lenses.

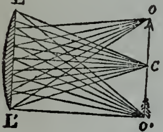
13. Assuming then, that by such combinations the image presented to the eye-glass is a faithful reproduction of the object, in its proper colours, perfectly distinct in all its lineaments, and sufficiently amplified, there is still one remaining condition for distinct vision, which is, that this image should be sufficiently bright. It will, therefore, be necessary here, to examine the conditions on which its brightness, or illumination, depends.

In the first place it is very evident that, other things being the same, the illumination of the image will be proportionate to that of the object, and in the inverse proportion of its superficial amplification; for the light which is transmitted from the object, being diffused over the surface of the image, will be necessarily more feeble as the superficial magnitude of the image is greater. The higher the magnifying power used, therefore, the greater is the necessity that the object should be intensely illuminated.

But the brightness of the image depends not only on the intensity of the illumination of the object, but also on the proportion of the light emanating from each point of the object, which arrives at the corresponding point of the image; and this, as we shall now show, will depend conjointly on the linear opening, or available diameter of the object-glass, and the distance of the object from it.

To make this more plain, let *o o′*, fig. 5, be the object, and L L′ the object-glass. We are to consider that each point of the object is a centre, from which rays emanate towards the object-glass; thus, for example, rays issuing from the point *c*, form a cone, of which the object-glass is the base, and of which *c* is the vertex; supposing all these rays to pass through the object-glass, and to be refracted by it, they will converge to the point of the image which corresponds to *c*.

Fig. 5.

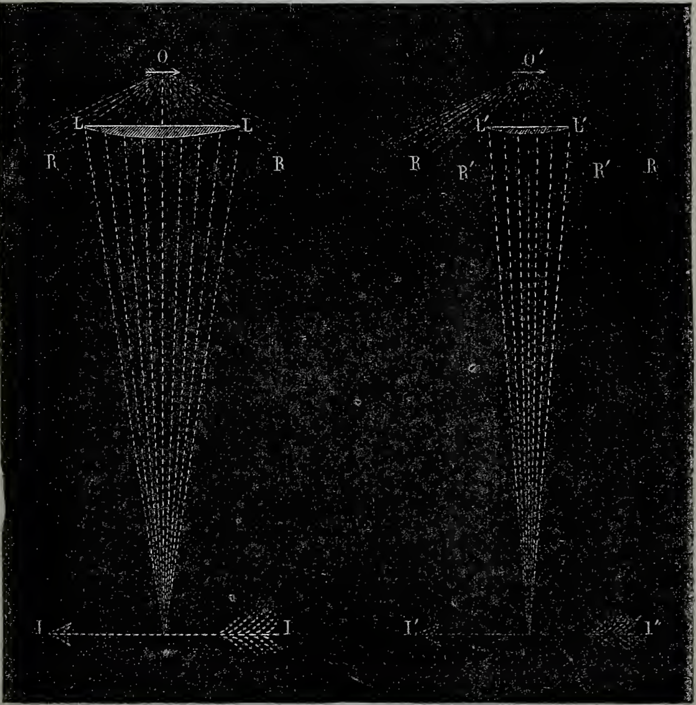


In the same manner, the rays which diverge from any other point, such as *o*, likewise form a cone, of which that point is the vertex, and the object-glass the base, and after passing through the lens, they will converge to the corresponding point of the object.

Thus it appears that each point of the image is illuminated by as many rays as are included within such a cone as we have here described; that is to say, one whose base is the object-glass, and whose vertex is on the object. But it is evident that the number of rays included in such a cone, depends exclusively upon the magnitude of its angle, that is the angle L *c* L′, formed by lines drawn from a point, *c*, upon the object.

14. This angle, which forms, therefore, an element of capital

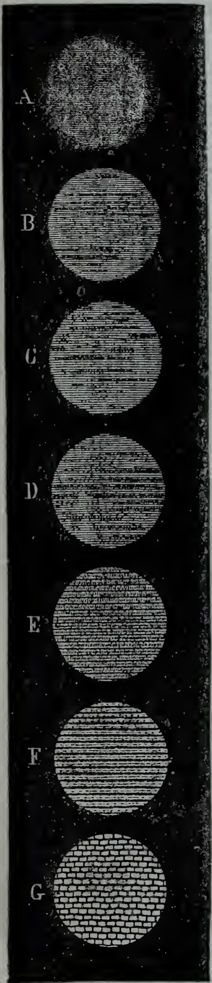
Fig. 6. Fig. 7.



importance in the estimation of the efficiency of the microscope, is called the ANGULAR APERTURE of the object-glass.

The effect produced by the variation of the angular aperture of the object-glass, other things being the same, will be rendered still more clearly intelligible by reference to figs. 6 and 7, where two lenses, L L and L′ L′, having equal focal lengths, are represented; the same object, O and O′, is placed at the same distances from them, and equal images of it, I I and I′ I′, are produced at equal distances from the lenses. The angular aperture of L L, being L O L, is greater than that of L′ L′, which is L′ O′ L′; and it is evident that a greater number of rays issuing from the object, will fall upon the lens L L, than upon L′ L′, in the proportion of the square of the angular aperture of the former to that of the latter; thus, if the angular aperture of L L be twice that of L′ L′, the number of rays which fall on L L will be four times the number which fall on L′ L′.

Fig. 8.



Supposing, then, that all the rays which fall upon each of the lenses, pass through them, and are made to converge upon corresponding points of the images I I and I′ I′, it is clear that each point of the image I I will be more intensely illuminated than the corresponding point of I′ I′, in the proportion of the square of the angular aperture of L L to that of L′ L′; and if these apertures be in the proportion above supposed of two to one, the several points of the image I I will be four times more intensely illuminated than those of I′ I′.

15. As a practical example of the effect of the angular aperture upon the image, we here give seven drawings made by the late Dr. Goring, of the appearance of a particle of dust, or a scale, as it is called, of a butterfly's wing, viewed with the same magnifying power, the angular aperture of the lens being successively augmented. When the aperture was reduced to the smallest limit, the object appeared as represented at A, fig. 8; when the aperture was increased in the proportion of 2 to 3, the object assumed the appearance represented at B, and, in short, by successively increasing the aperture, it assumed the appearances shown in C, D, E, F, and G. It will be

evident, therefore, that by the mere effect of this increased illumination, the lineaments showing the structure of the object, which were altogether imperceptible in C and D, began to be developed but very imperfectly in E, were more visible in F, and became quite distinct in G.

The great and manifest importance, therefore, of the angle of aperture to the efficiency of the microscope, renders it indispensable that easy and practicable means should always be attainable for determining it. If the distance of the object from the object-glass, and the virtual opening or diameter of the object-glass could be always exactly measured; and if all the rays which fall on the object-glass could be assumed to pass through it, and to converge upon the image, then the angular aperture would be an element of very easy calculation. But it is not practicable to obtain these data, and it cannot be assumed that all the rays which are incident upon the object-glass will pass through it, and be made to converge upon the image.

16. Instead, therefore, of calculating the angular aperture in this manner, it is determined by immediate experiment.

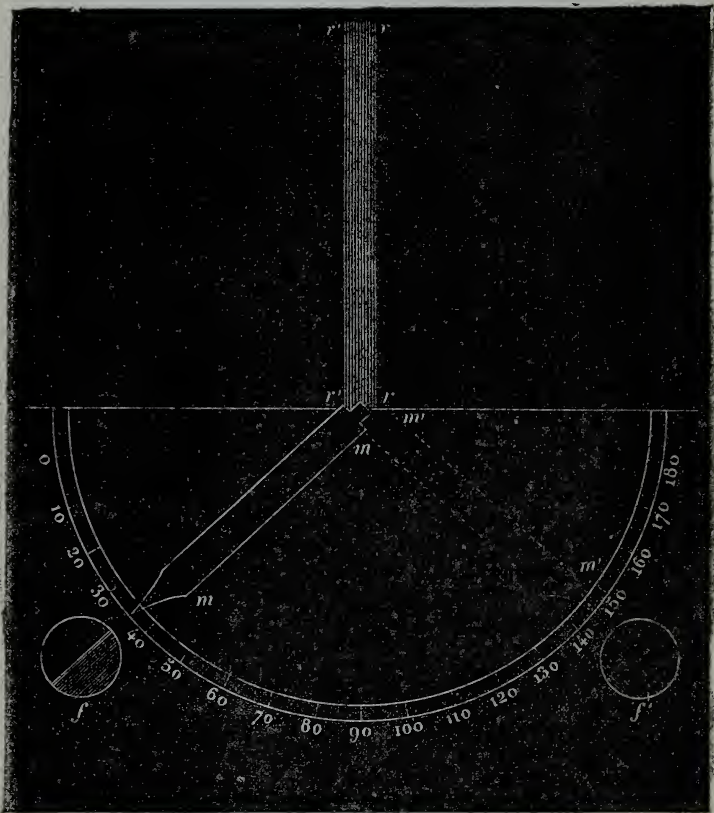
The greatest angle of aperture of which a given lens is capable, will be found by determining the greatest obliquity with which it is possible for rays to fall upon the object-glass, so as to be refracted by it to the eye-glass. The following method of ascertaining this, for any given object-glass, was contrived and practised by Mr. Pritchard, at an early epoch in the progress of the improvement of the microscope, when the importance of the angular aperture was demonstrated by that eminent artist and Dr. Goring. The same method, with but little modification, is that still practised by opticians.

Let *m m*, fig. 9, be the microscope, the object end being fixed upon a pivot, so that the eye end can be moved over a graduated semicircle. Let a small luminous object, such as the flame of a candle, be placed in the direction *r r*, at the distance of 6 or 8 feet, so that the rays proceeding from it to the object-glass may be considered as parallel. If the microscope be directed towards the candle, all the rays will fall perpendicularly on the object-glass, and will evidently pass through it to the eye-glass. If the microscope be then turned on the pivot to the left, the rays will fall more and more obliquely on the object-glass, and a less and less number of them will pass to the eye-glass.

When such a position as *m m* is given to the microscope, those rays only which fall upon the border of the object-glass upon the right of the observer, will arrive at the eye-glass, and the field of view will then appear, as shown at *f*, half illuminated and half dark. If the microscope be moved beyond this position, the field will be entirely dark, no rays being transmitted to the eye-glass.

If the microscope, on the contrary, be moved to the other side of the graduated semicircle, the same appearances will be produced, and when it assumes the position *m′ m′*, the field will be again half illuminated, and beyond that point it will be dark.

Fig. 9.



The arc of the graduated semicircle, included between the two positions *m m* and *m′ m′*, will then be the measure of the angular aperture of the object-glass, since that arc will correspond with the greatest obliquity, at which rays diverging from the object to the object-glass, can pass through the latter, so as to arrive at the eye-glass.

Such are then, generally, the means by which the three conditions of distinct vision with the microscope will be fulfilled. The second of these conditions, that which involves the complete correction of the chromatic aberration, will, however, require here some further development, since it involves circumstances which have demanded the greatest artistic skill on the part of the makers.

17. It has been shown in our Tract upon "Optical Images," 53 *et seq.*, that the chromatic aberration of lenses is corrected by combining together two lenses, one of flint and one of crown glass, which have different effects upon the separation of the coloured images, the curvatures of their surfaces being so related, the one to the other, that the separation which would be produced by either is exactly counteracted by an equal separation in a contrary direction by the other. If the curvatures, however, of the two lenses be not so related as to produce this exact compensation, they may either give a predominance to the effect of the one or the other, so as to produce chromatic aberrations of opposite kinds; the coloured images thus produced being ranged in a contrary order.

When a single convex lens is used, the most refrangible rays are brought to a focus, nearer to the lens than the least refrangible; and consequently the violet and blue images are formed nearer to the lens than the red and orange. This is called POSITIVE CHROMATIC ABERRATION.

If by combining two lenses of flint and crown glass this aberration be more than compensated, that is, if the blue and violet images are not merely brought to coincide with the red and orange ones, so as to render the lens achromatic, but made to interchange place with them, so that the red and orange shall be nearest to, and the blue and violet farthest from the lens, the chromatic aberration will be NEGATIVE.

The importance of this in the practical construction of the microscope will presently appear.

It must be remembered that the microscope consists of the object-glass, the field-glass, and the eye-glass, and that its efficiency depends not merely upon the fidelity of the image produced by the object-glass, but upon that which is seen by the observer looking through the eye-glass. This last must be an exact reproduction of the object in form and colour.

Now it is easy to show that if the object-glass be absolutely achromatic, the image seen by the observer through the eye-glass will not be so; for, in that case, the rays forming the image produced by the object-glass passing successively through the field-glass and the eye-glass, neither of which are achromatic, the image viewed by the observer through the eye-glass must be affected by as much positive aberration as is due to the combination of the field-glass and the eye-glass.

This defect might, it is true, be remedied by making both the field-glass and eye-glass achromatic; but independently of other objections to such an expedient, it would be needlessly expensive; and the same purpose is attained in a much more simple manner, upon the principles of positive and negative chromatic aberrations, which have just been explained.

The method practised for this purpose may be briefly and generally explained thus: The field-glass and the eye-glass being simple convex lenses, produce positive chromatic aberration. The object-glass, on the other hand, being a compound lens, may be so constructed, according to what has been just explained, as to produce negative chromatic aberration.

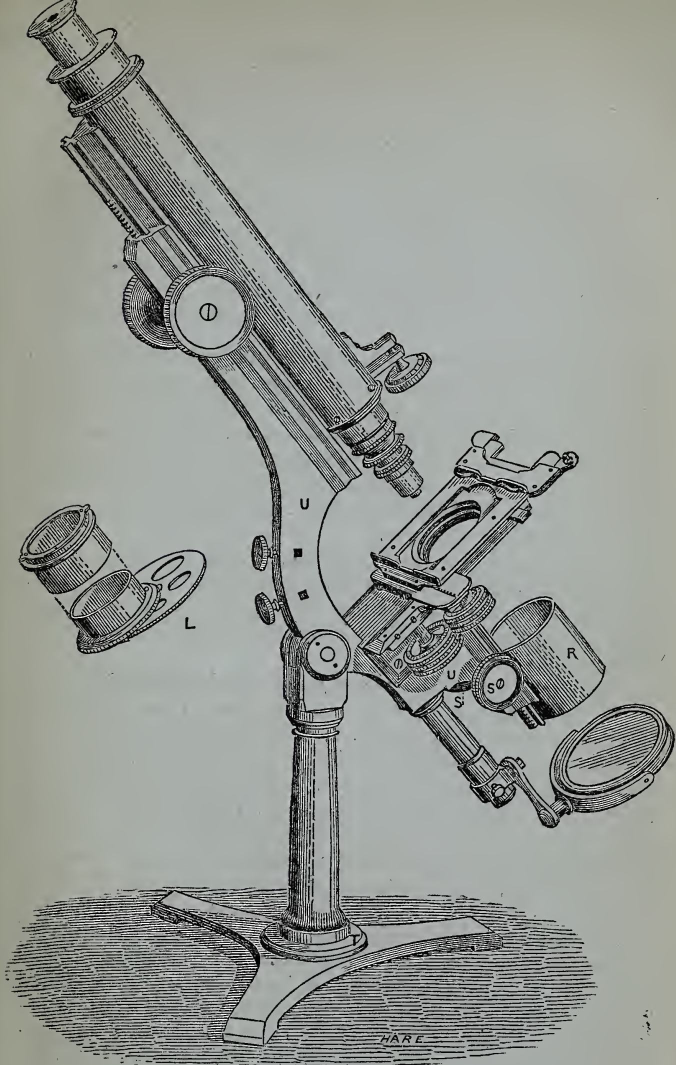


Fig. 42 —SMITH AND BECK'S MICROSCOPE.

THE MICROSCOPE.

CHAPTER II.

Mutual chromatic and spherical correction of the lenses (Continued).—18. Centering.—19. Compound object-pieces.—20. The eye-piece.—21. Various magnifying powers adapted to the same microscope.—22. Actual dimensions of the field of view.—23. Means of moving and illuminating the object.—24. Focussing.—25. Preparation of the object.—26. General description of the structure of a microscope.—27. The stage.—28. The illuminators.—29. The diaphragms.

Now let us suppose that the entire combination of lenses is so formed, that the negative chromatic aberration produced by the object-glass shall be exactly equal to the positive chromatic aberration, produced by the field-glass and the eye-glass. In that case, it is evident that the one aberration will extinguish the other, and that the image viewed by the observer through the eye-glass will be an exact reproduction of the object, being exempt from all aberration whatever.

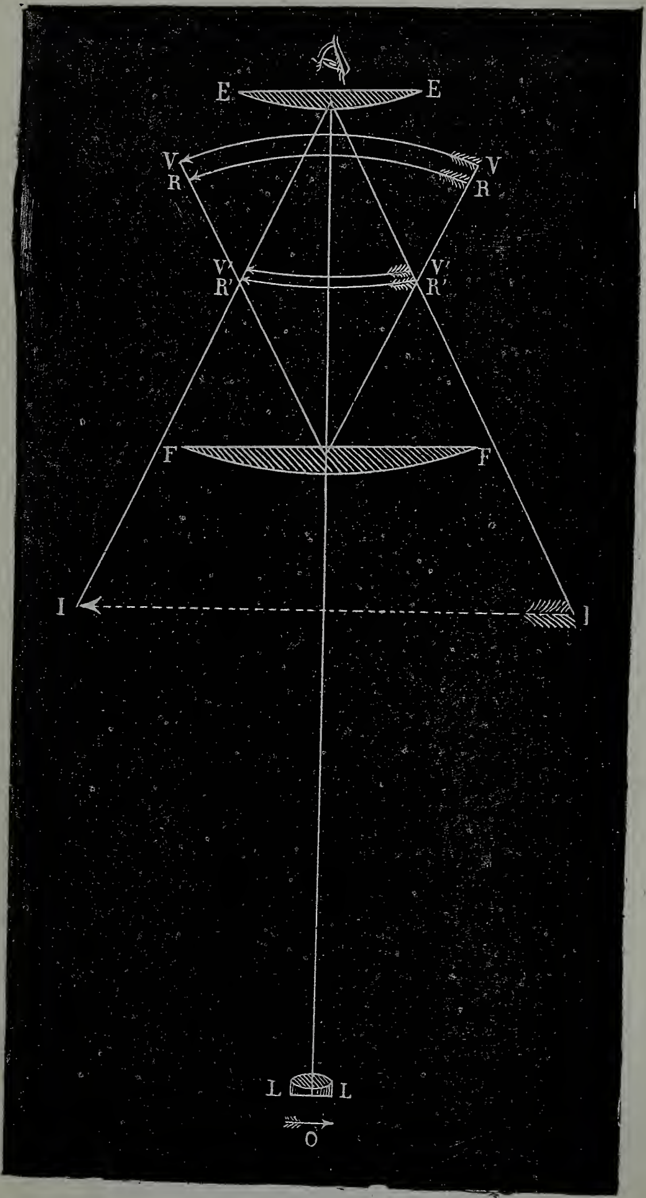
To make this more evident, Let LL, fig. 10, be the compound object-glass, consisting of a double convex lens of crown glass, and a plano-concave lens of flint-glass, formed so as to produce negative chromatic aberration; let F F be the field-glass; E E the eye-glass, and O the object.

Let V V R R be the coloured images of the objects, which would be produced by L L, if F F were not interposed; these images will be slightly concave towards L L, according to what has been explained in our Tract upon "Optical Images," 47 *et seq.*; and since L L is supposed to have negative aberration, the red images R R will be nearest to it, and the violet ones, V V, most remote from it.

But the rays which would converge upon the various points of these images being intercepted by the field-glass F F, are rendered more convergent by it, and the images are accordingly formed nearer to it. This lens, F F, also increases the convergence of the violet rays which are most refrangible, more than it increases that of the red rays which are least refrangible. The consequence of this is, that the violet and red images are brought closer together than they were, as shown in the figure; but still the violet images are more distant from F F than the red, so that the chromatic aberration of L L and F F conjointly is still negative, though less than the aberration of L L alone.

There is another effect produced by the lens F F which it is important to notice. The images produced by L L, which were slightly concave towards F F, are changed in their form, so as to be slightly concave towards E E. The cause of this change has been already explained in our Tract upon "Optical Images," 46.

Fig. 10.



In fine, then, the rays diverging from the images R′ R′ V′ V′, after passing through the eye-glass E E, have their divergence diminished, so as to diverge from more distant points, I I. The divergence of the violet rays, V′ V′, being most refrangible, is most diminished, and that of the red rays, R′ R′, being least refrangible, is least diminished. If their divergence were equally diminished, a series of coloured images would be formed at I I, the violet being nearer to, and the red farther from E E; but the divergence of the violet, which is already greater than the red, is just so much greater than the latter, that the difference of the effects of E E upon it is such as to bring the images together at I I.

Thus it appears, that the positive aberration of the eye-glass E E is exactly equal to the negative aberration of L L and F F taken conjointly, so that the one exactly neutralises the other, all the coloured images coalescing at I I, and producing an image altogether exempt from chromatic aberration.

There is another important effect produced by the eye-glass; the images R′ R′ V′ V′, which are slightly concave towards E E, are rendered straight and flat at I I; the principle upon which this change depends has been also explained in our Tract upon "Optical Images," 46.

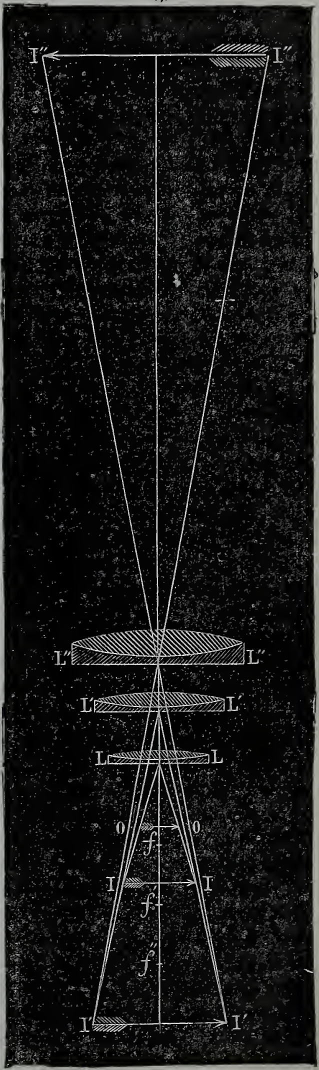
Thus, it appears that, by this masterly combination, a multiplicity of defects, chromatic, spherical, and distortive, are made, so to speak, to extinguish each other, and to give a result, practically speaking, exempt from all optical imperfection.

18. There is still another source of inaccuracy which, though it is more mechanical than optical, demands a passing notice. All the lenses composing the microscope require to be set in their respective tubes, so that their several axes shall be directed in the same straight line with the greatest mathematical precision. This is what is called CENTERING the lenses, and it is a process, in the case of microscopes, which demands the most masterly skill on the part of the workman. The slightest deviation from true centering would cause the images produced by the different lenses to be laterally displaced, one being thrown more or less to the right and the other to the left, or one upwards and the other downwards; and even though the aberrations should be perfectly effaced, the superposition of such displaced images would effectually destroy the efficiency of the instrument.

19. In what precedes, we have, to simplify the explanation, supposed the object-glass to consist of a single achromatic lens, a circumstance which never takes place except when very low powers are sufficient. A single lens, having a very high magnifying power, would have so short a focus and such great curvature, that it would be attended with great spherical aberration, inde-

pendently of other objections; great powers, therefore, have been obtained by combining several achromatic lenses in the same object-piece, so that the rays proceeding from the object are successively refracted by each of them, and the image submitted to the eye-glass is the result of the whole.

Fig. 11.



The optical effect of such a combination will be more clearly understood by reference to fig. 11, where L L, L′ L′, and L″ L″, represent a combination of three achromatic object-glasses. Let O O be the object, placed a little within the focus f of the lens L L. The image of O O, produced by L L, would then be an imaginary one in the position I I; (see Tract on "Optical Images," 35, *et seq.*). After passing through L L, the rays, therefore, fall upon L′ L′, as if they diverged from the several points of the image I I, which may, therefore, be considered as an object placed before the lens L′ L′. Let f' be the focus of L′ L′; the image of I I produced by L′ L′ will therefore be imaginary, and will be at I′ I′; the rays after passing through L′ L′ will fall upon L″ L″, as if they diverged from the several points of I′ I′. This image I′ I′, therefore, may be considered as an object placed before the lens L″ L″. Let f'' be the focus of this lens; the image of I′ I′ produced by L″ L″ will then be I″ I″, and will be real; this will then, in fact, be the image transmitted to the eye-piece.

To render the diagram more easy of comprehension, we have not here attempted to represent the several distances in their proper proportions.

The compound lenses, of which object-pieces consist, are generally, as represented in the figure, plane on the sides presented towards the object. This is attended, among other advantages, with that of allowing a larger angle of aperture than could be obtained if the surface presented to the rays diverging from the object were convex.

The extreme rays diverging from each point of the object fall upon the surface of the object-glass with a greater and greater obliquity as they approach its borders, and since there is an obliquity so extreme that the chief part of the rays would not enter the glass at all, but would be reflected from it, the angle of aperture must necessarily be confined within such limits, that the rays falling from the borders of the lens will not be so oblique as to come under this condition. If the surface of the object-glass presented to the object were convex, it is evident that the rays diverging from an object at a given distance from it would fall upon its borders with greater obliquity than if it were plane, and, consequently, such an object-glass would allow of a less angle of aperture than a plano-convex one with its plane side towards the object.

Improvements have recently been made in object-glasses, by which angles of aperture have been obtained so great, as not to admit even of a plane surface being presented to the diverging pencil, and it has accordingly been found necessary, in such cases, to give the object-glasses the meniscus form (Optical Images, 25), the concave side being presented to the object. By this expedient angles of aperture have been obtained so great as 170°. If the surface of the object-glass presented to the object were plane, the extreme rays of the central pencils, with such an angle of aperture, would fall upon the surface of the lens with obliquities of not more than 5°, and the obliquities of the extreme rays of the lateral pencils would be even less. Under such circumstances, the chief part of the rays near the borders of the lens would be reflected, and, consequently, its virtual would be less than its apparent angle of aperture. It is questioned by some microscopists that even with the expedient of a concave external surface, a practically available angle of aperture so great as 170° can be obtained.

The three achromatic lenses here described being mounted, so that their axes shall be precisely in the same straight line, constitute what is generally called an OBJECT-GLASS, but which, perhaps, might with more convenience and propriety be denominated an OBJECT-PIECE.

The power of the object-pieces is usually indicated by the makers, by assigning their focal lengths; but as these object-pieces are composed of several lenses, having different focal lengths, it is necessary to explain what is meant by the focal length of the combination.

Let L be a single convex lens, and O the compound object-piece; suppose then, the same object placed successively at the same distance from L and O, and let L have such a convexity that it will produce an image, I, of the object equal to the image I′, which the object-piece, O, produces, and that the distance of this image, I, from the single lens L, is equal to the distance of the image I′ from the object-piece O. In that case, the single convex lens L, being, in fact, the optical equivalent of the compound object-piece O, its focal length is taken to be that of the object-piece O. Thus, for example, if the lens L, having a focal length of one inch, produce the same image of the same object similarly placed before it, as would the object-piece O, then the focal length of the object-piece O is said to be one inch.

In short, the single lens L, and its equivalent compound object-piece O, differ only in this, that the images produced by L are defaced more or less by aberration, from which the images produced by O are altogether exempt.

These object-pieces are sold by some makers so fixed that their component lenses are inseparable, the observer being unable to use any one of them as an object-glass without the others; other makers, however, mount them in such a manner that the first and second lenses, L L and L′ L′, may be unscrewed or drawn off, and the lens L″ L″ alone used as the object-glass; or L′ L′ may be screwed on, the two lenses L′ L′ and L″ L″ then making an object-piece of greater power; by this arrangement the observer obtains, without increased expense, three object-pieces of different powers.

After what has been said, however, of the exact manner in which the aberrations of the field and eye glasses are corrected and balanced by the contrary aberration of the object-piece, it will be easily understood, that the economy by which three powers are thus obtained, is gained at the expense of the efficiency of the instrument; for if the aberrations of the triple object-piece are so adjusted as exactly to balance those of the other lenses, that balance will no longer be maintained when the lens L L; and still less when the lens L′ L′, is removed. It is on this account that some makers, who are the most scrupulous as to the character of their instruments, refuse to supply separable object-pieces.

The imperfection, however, produced in this case by disturbing the balance of the aberrations is of less importance, inasmuch as by removing the lens L L, and still more by removing L′ L′, the magnifying power is so considerably diminished, that the defects of the image produced by the unbalanced aberrations are very inconsiderable, and the observer is generally content to tolerate them on account of the great economy gained by the separation of the lenses, which supplies, without additional expense, three independent object-pieces.

Some of the foreign makers, less scrupulous in the exact adjustment of their optical combinations, make all the three lenses composing each triple object-piece exactly similar, unscrewing one from another, so as to enable the observer to use one, two, or three at pleasure. It is evident that, with such combinations, the aberrations can never be so exactly balanced as they are in the object-pieces above described; but in the instruments to which they are applied, powers exceeding 700 or 800 are almost never attempted, and the aberrations, though imperfectly compensated, are sufficiently so to prevent much injurious confusion in the images.

In the superior class of instruments, where magnifying power is pushed to so extreme a limit as 1500 or 2000, the most extreme precision in the balance of the aberrations must necessarily be realised, since the slightest imperfection so prodigiously magnified would become injuriously apparent.

The extreme degree of perfection, which has been attained in the best class of microscopes, may be imagined, when it is stated, that an object which is distinctly visible under a power of 1500 or 2000, when it is exposed to the object-glass uncovered, will be sensibly affected by aberration if a piece of glass, no more than the 100th of an inch in thickness, be laid upon it. Infinitesimally small as is the aberration produced by such a glass film, it is sufficient, when magnified by such a power, to be perceptible, and to impair in a very sensible manner the distinctness of the image.

As it has been found necessary, for the preservation of microscopic objects, to cover them with such thin films of glass, through which, consequently, they are viewed, adjustments are provided in microscopes with which the highest class of powers are supplied, by which even the small aberration due to these thin plates of glass thus covering the objects can be corrected. This is effected by mounting the lenses, which compose the triple object-piece, in such a manner that their mutual distances, one from another, can be varied within certain small limits, by motions imparted to them by fine screws. This change of mutual distance produces a small effect upon the aberrations, rendering their total results negative to an extent equal to the small amount of positive aberration produced by the thin glass which covers the object.

20. The eye-glass and the field-glass are both plano-convex

lenses, having their plane sides turned towards the eye; they are set in opposite ends of a brass tube, varying in length from two inches downwards, according to their focal lengths, the distance between them and, consequently, the length of the tube being always equal to half the sum of their focal lengths.

The higher the power of the eye-piece, and consequently the shorter the focal length of the eye-glass, the less will be the length of the tube in which they are set.

This tube is called the EYE-PIECE.

It will be apparent from what has been explained, that the magnifying power of the instrument will depend conjointly on those of the object-piece and eye-piece.

21. In the prosecution of microscopic researches, the use of very various magnifying powers is indispensable; the higher powers would be as useless for the larger class of objects, as the lower ones for the smaller. But even for the same object, a complete analysis cannot be accomplished without the successive application of low and high powers: by low powers the observer is presented with a comprehensive view of the entire form and outline of the object under examination, just as an aëronaut who ascends to a certain altitude in the atmosphere obtains a general view of the country, which would be altogether unattainable upon the level of the ground. By applying successively higher powers, as has been already explained, the smaller parts and minuter features of the object are gradually disclosed to view, just as the aëronaut, in gradually descending from his greatest altitude, obtains a view of objects which were first lost in the distance, but at the same time loses, by too great proximity, the general outline.

The microscope-makers, therefore, supply in all cases an assortment of powers, varying from 30 or 40 upwards; observations requiring powers under 40, being more conveniently made with simple microscopes. For this purpose it is usual, with the best instruments, to furnish six or eight object-pieces and three or four eye-pieces, each eye-piece being capable of being combined with each object-piece. The number of powers thus supplied will be equal to the product of the number of object-pieces, multiplied by the number of eye-pieces.

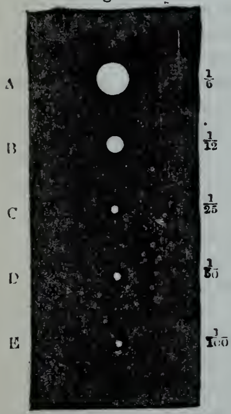
The powers, however, may still be further varied, by provisions for changing the distance between the object and eye-pieces, within certain limits. For this purpose, the tube of the instrument is sometimes divided into two, one of which moves within the other, like the tube of a telescope, the motion being produced by a fine rack and pinion: in this case the eye-piece is inserted in one of the tubes, and the object-piece in the other. By combining this provision with a proper assortment of object-pieces and eye-pieces, all possible gradations of power between the highest attainable, and the lowest which is applicable, can be obtained.

The actual magnitude of the space which can be presented at once to the view of the observer, will vary with the magnifying power; but in all cases it is extremely minute. Thus, with the lowest class of powers, where it is largest, it is a circular space, the diameter of which does not exceed the 8th or 10th of an inch; it follows, therefore, that no object, the extreme limits of whose linear magnitude exceed this, can be presented at once to the view of the observer. Such objects can only be seen in their ensemble, by means of less powerful magnifying glasses, or with the naked eye.

22. The field of view, with powers from 100 to 300, varies in diameter from the 15th to the 40th of an inch; from 300 to 500 it varies from the 40th to the 70th of an inch; and from 500 to 700 from the 70th to the 100th of an inch.

It will thus be understood, that even with the moderate power of 700, an object to be included wholly within the field of view, must have a magnitude such as may be included within a circle whose diameter does not exceed the 100th of an inch. These observations will be more clearly appreciated by reference to the annexed diagram, fig. 12, where A is a circle whose diameter is the 6th of an inch; B one whose diameter is the 12th of an inch; C the 25th, D the 50th, and E the 100th.

Fig. 12.



But when still higher powers are used, the actual dimensions of the entire space comprised within the field of view will be so very minute, that an object which would fill it, and still more, smaller objects included within it, would not only be altogether invisible to the naked eye, but would require considerable microscopic power to enable the observer to see them at all.

The actual dimensions of the field of view, which correspond to each magnifying power, vary more or less in different instruments. Those which I have given above, are taken from a microscope made by Charles Chevalier, which is in my possession. The difference however in this respect, between one instrument and another, is not considerable, and the above will serve as a fair illustration of the limits of the field of instruments in general.

The entire dimensions of the field of view therefore being so exceedingly minute, it will be easily understood that some difficulty will attend the process by which a small object, or any particular part of an object, can be brought within it: thus, with a moderate power of 500, the entire diameter of the field being no more than the 70th of an inch, a displacement of the object to that extent, or more, would throw it altogether out of view. If therefore the object, or whatever supports it, be moved by the fingers, the sensibility of the touch must be such as to be capable of producing a displacement thus minute.

If the object be greater in its entire dimensions than the field of view,—a circumstance which most frequently happens,—a part only of it can be exhibited at once to the observer; and to enable him to take a survey of it, it would be necessary to impart to it, or to whatever supports it, such a motion as would make it pass across the field of view, as a diorama passes before the spectators, disclosing in slow succession all its parts, and leaving it to the power of the observer to arrest its progress at any desired moment, so as to retain any particular part under observation.

The impracticability of imparting a motion so slow and regular by the immediate application of the hand to the object, or its support, will be very apparent, when it is considered that while the entire object may not exceed a small fraction, say, for example, the 20th of an inch in diameter, the entire diameter of the field of view may be as much as 20 times less, so that only a 20th part of the diameter of the object would be in any given position comprised within it.

23. These and similar circumstances have rendered it necessary that the want of sufficient sensibility and delicacy of the touch in imparting motion to the object, shall be supplied by a special mechanism, by means of which the fingers are enabled to impart to the object an infinitely slower and more regular motion, than they could give it without such an expedient. The means by which this is accomplished will be presently explained.

We have seen that the intensity with which the microscopic image is illuminated depends on the angle of aperture, other things being the same; but however large that angle may be, when considerable magnifying power is used, it is necessary that the object itself should be much more intensely illuminated than it would be by merely exposing it to the light of day, or that of the most brilliant lamp. It is therefore necessary to provide expedients, by which a far more intense light can be thrown upon it.

24. The instrument is said to be in FOCUS when the observer is enabled to see with the eye-glass the magnified image of the

object with perfect distinctness; this will take place provided the mutual distances between the eye-piece, the object-piece, and the object are suitably adjusted; and this adjustment may be accomplished by moving any one of these three towards or from the other two, while these last remain fixed: thus, for example, if the object and the object-piece remain unmoved, the instrument may be brought into focus by moving the eye-piece to or from the object-piece. The rack and pinion, already described, which moves the tube in which the eye-piece is inserted, can accomplish this. This provision, however, is not made in all microscopes.

If the eye-piece and the object be fixed, the instrument may be brought into focus by moving the object-piece to or from the object. To effect this, it would be necessary that the object-piece should be inserted in a tube, moved by a rack and pinion, like that of the eye-piece.

In fine, if the object-piece and eye-piece be both fixed, the instrument may be brought into focus by moving the object, or whatever supports it, to or from the object-glass.

All these methods are resorted to in the different forms in which microscopes are mounted by different makers.

25. Since nearly all material substances, when reduced to an extreme degree of tenuity, are more or less translucent, and since almost all microscopic objects have that degree of tenuity by reason of their minuteness, it happens that nearly all of them are more or less translucent; and where in exceptional cases a certain degree of opacity is found, it is removed without interfering with its structure, by saturating the object with certain liquids, which increase its translucency, just as oil renders paper semi-transparent. The liquid which has been found most useful for this purpose, is one called CANADA BALSAM. When the object is saturated with this liquid, it is laid upon a slip of glass, about two inches long and half an inch wide, and is covered with a small piece of very thin glass, made expressly for this purpose, the thickness in some cases not exceeding the 100th of an inch. It is usual to envelope the oblong slip of glass, in the middle of which the object is thus mounted with paper gummed round it, a small circular hole being left uncovered on both sides of the glass, in the centre of which the object lies.

The slips of glass thus prepared, with the objects mounted upon them, are called *slides* or *sliders* · and the objects thus mounted are so placed, that the axis of the object-piece shall be directed upon that part of them which is submitted to observation, provisions being made to shift the position of the slider, so as to bring all parts of the object successively under observation. Further provisions are also made to throw a light upon the object, by which it will be seen as an object is on painted glass.

Since, however, there are some few objects which cannot be rendered translucent, expedients must be provided, by which they can be illuminated upon that side of them which is presented to the microscope. It is often necessary, also, even in the case of translucent objects, that they should be viewed by means of light thrown upon that side of them which is turned to the object-glass.

26. These general observations being premised, we shall proceed to explain the method by which the optical part of the instrument is mounted, and the several accessories by which the object is supported, moved, and illuminated.

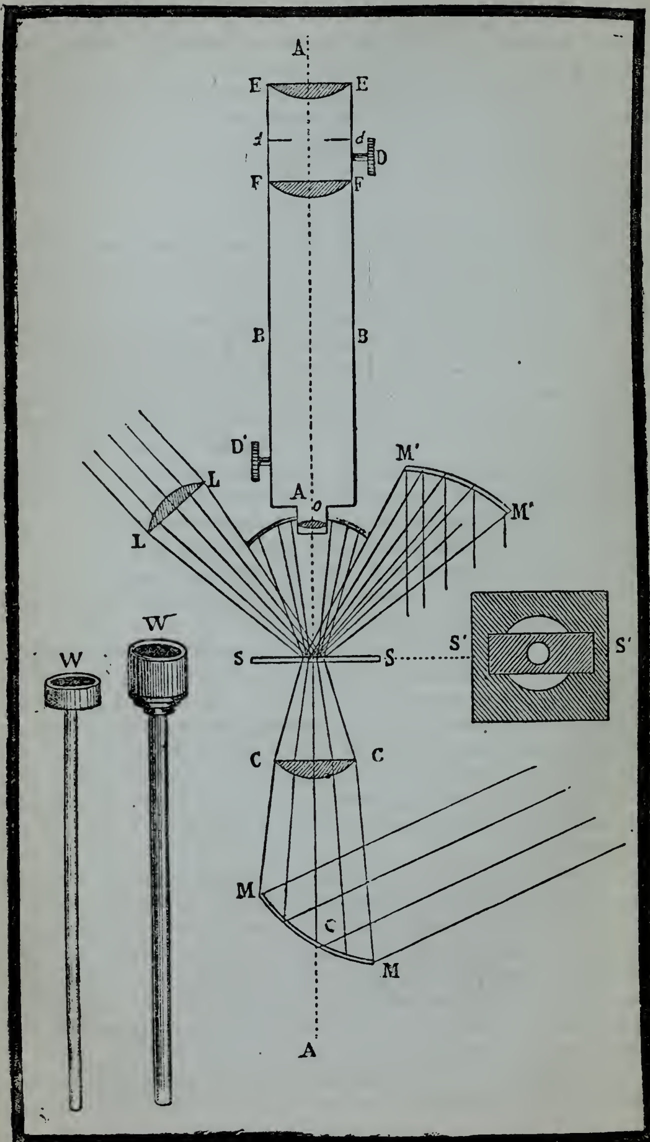
Let us suppose, for the present, that the eye-piece E F, fig. 13, and the object-piece *o*, are mounted in a vertical tube, with whose axis A A A, the several axes of the lenses, accurately coincide. Let *d d* be a diaphragm, or blackened circular plate, with a hole in its centre, placed in the focus of the eye-glass, by which all rays of light not necessary to form the image shall be intercepted. Let D be a milled head, by turning which the tube which carries the eye-piece can be moved within certain limits to and from the object-piece, and let D′ be another milled head, by which the tube which carries the object-piece can be moved within certain limits to and from the object, or by which the entire body B B of the microscope, carrying the object-piece and eye-piece, can be moved to and from the object.

27. Let S S be a flat stage of blackened metal or wood, having a circular hole in its centre, as shown in plan at S′ S′, and let it be fixed by proper arrangements, so that the axis A A A of the microscope shall pass through the centre of the circular aperture, and so that its plane shall be at right angle to that axis. Let a slider, such as we have described above, upon which an object is mounted, be laid upon this stage, so that the object shall be in the centre of the hole, and therefore in the axis A A A of the microscope.

28. Let M M be a concave reflector, receiving light either from a lamp or a window, and reflecting it upwards towards the opening in the slider, in converging rays, so as to condense the light with more or less intensity upon the under side of the object; if the convergence produced by M M be insufficient, it may be augmented by the interposition of a convex lens C C. This may or may not be interposed, according as the object is smaller or greater, and requires a more or less intense illumination.

The light being thus thrown upon the lower side of the object, the latter, being sufficiently translucent, is rendered visible by it.

Fig. 13.

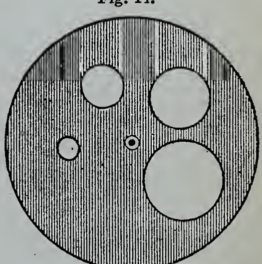


If the object be opaque, it may be illuminated from above by several expedients; being placed upon a blackened plate resting on the stage S S, light proceeding from a window or a lamp may be condensed upon it by a concave reflector M′ M′, or by a convex lens L L. These arrangements, however, are only applicable when the object is at such a distance from the object-piece that the light proceeding from M′ M′ or L L shall not be wholly or partially intercepted by the object-piece. This would always be the case, however, when very high powers are used, and when, consequently, the object must be brought very close to the object-piece. In that case, the object is supported upon a small piece of blackened cork, or in a dark cell of the form represented at W W; this support is placed in the centre of the opening of the stage, so as not to intercept any but the central rays reflected from M M; upon the end of the object-piece a concave reflector, having a hole in its centre, through which the object-piece passes, is fixed; the light proceeding from M M, and falling upon this reflector, is reflected by it, so as to converge upon the object, and thus to illuminate it.

A concave illuminator thus mounted is called, from its inventor, a *lieberkuhn*.

29. In the illumination of objects it is frequently necessary to limit, to a greater or less extent, the diameter of the pencil of light thrown from the reflector, M M, upon the object. Although this may partly be accomplished by varying the distance of the reflector from the object, or by the interposition of a convex lens, such expedients are not always the most convenient, and a much more ready and effectual method of attaining this end is supplied by providing below the stage, S S, a circular blackened disc, capable of being turned upon its centre in its own plane. This disc is pierced with a number of holes of different diameters, as shown in fig. 14, and it is so mounted, that the openings in it, by turning it round its centre, may be brought successively under the object. This is easily done by fixing the centre of this disc at a distance from the centre of the stage, equal to the distance between the centre of the disc and the centres of the holes made in it.

Fig. 14.



This appendage is called the *disc of diaphragms*, and is of great use in the illumination of objects, as will appear hereafter.

As the effect of the illuminators varies not only with their distance from the object, but also with the direction in which the light directed from them falls upon the object, provisions are made in mounting the microscope, by which various positions may be given to them, so that the light may fall upon the object in any desired manner.

In the frame in which the illuminator, M M, is mounted, it is customary to place two reflectors, one at each side, one concave and the other plane. By the former a converging, and by the latter a parallel pencil of light is reflected towards the object.

In this general illustration we have supposed the axis of the instrument to be vertical; it may, however, have any direction whatever; but whatever be its direction, the stage, S S, must always be at right angles and concentric with it. The eye-piece and object-piece are also supposed to be set in the same straight tube, with their axes set in the same straight line. This arrangement, though most commonly adopted, is neither necessarily nor always so. The tube which carries the eye-piece may, on the contrary, be inclined, at any desired angle, with that which carries the object-piece; for this purpose it is only necessary to place in the angle formed by the two tubes a reflector, so inclined that the rays coming from the object-piece shall be reflected along the axis of the tube which carries the eye-piece.

Fig. 46.—NACHET'S MULTIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER III.

30. Oblique plane reflectors. THE SUPPORT AND MOVEMENT OF THE OBJECT: 31. The stage.—32. Mechanism for focussing.—33. Coarse adjustment.—34. Fine adjustment.—35. Method of determining the relief of an object.—36. Difficulty of bringing the object into the field.—37. Mechanism for that purpose.—38. Mechanism to make the object revolve.—39. Object to be successively viewed by increasing powers.—40. Slides to be cleaned.—41. Compressor.—42. Apparatus for applying voltaic current. THE ILLUMINATION OF OBJECTS: 43. Curious effects of light on objects.—44. Illumination by transmission and reflection.—45. Microscopic objects generally translucent, or may be made so.—46. Effects of varying thickness.—47. Varying effects of light and shade.—48. Uses of the Lieberkuhn.—49. Effects of diffraction and interference.—50. Use of daylight.—51. Artificial light.—52. Protection of the eye.—53. Pritchard's analysis of the effects of illumination.

30. Thus, for example, if the tube which carries the object-piece be vertical, a plane reflector, M M, fig. 15, receiving the rays

Fig. 15.

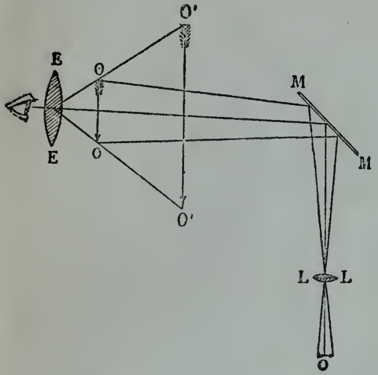
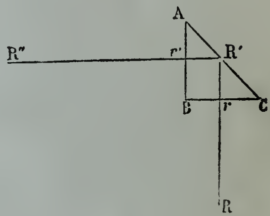


Fig. 16.



coming in a vertical direction from the object-piece, will reflect them horizontally to the eye-piece E E.

The same object would be attained with more advantage, and less loss of light, by means of a rectangular prism, A B C, fig. 16,

Fig. 17.

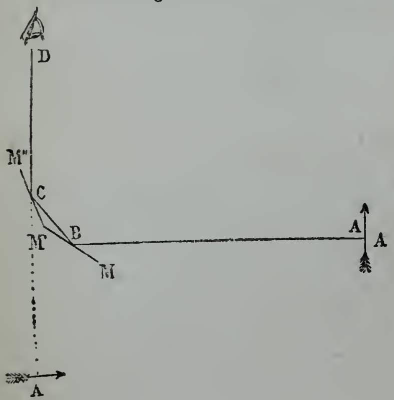
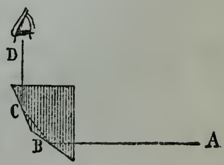


Fig. 18.



the vertical ray, R R′ being reflected by the back, A C, of the prism in the horizontal direction R′ R″.

Since a single reflection thus made produces an inverted image, it is sometimes preferable to accomplish the object by two successive reflections, as shown in fig. 17, where the ray, A B, is successively reflected at B and C to the eye at D. And the same object may be attained more advantageously by means of a quadrangular prism, as shown in fig. 18.

This application of the prism and reflector has been already explained in our Tract upon Optical Images.

Much practical convenience often arises from the adoption of this expedient; thus, while the object-tube is directed vertically downwards, to an object supported on a horizontal stage, or floating on or swimming in a liquid, the eye-tube may be horizontal, so that the observer may look in the level direction. In this case the two tubes are fixed at right angles, the reflecting surface being placed at an angle of 45° with their axes. We shall see hereafter a case in which, by the adoption of an oblique tube, several observers may at the same time, looking through different eye-pieces, see the same object through one and the same object-glass.

THE SUPPORT AND MOVEMENT OF THE OBJECT.

31. The appendage of the microscope, adapted for the support of the object is called THE STAGE.

Since every motion or disturbance by which the stage may be affected will necessarily be increased, when seen through the microscope, in the exact proportion of the magnifying power, it is of the utmost importance that it should be exempt from all tremor, and that it should have strength sufficient to bear, without flexure, the pressure of the hands in the manipulation of the object. When a high power is used, the focal adjustment of the instrument requires to be so exact, that a displacement of the object, which would be produced by the slightest pressure of the fingers upon a stage not very firmly supported, would throw it out of focus.

If the instrument be used for dissection, or any other purpose in which steady manipulation of the object is needed, it will be found convenient that the stage have sufficient magnitude to support both wrists, while the operation is performed with the fingers. Supports for the elbows ought also to be arranged, so as to place the operator completely at ease.

32. The instrument is focussed, as already explained, either by moving the stage to and from the body, or by moving the body to and from the stage. The motion is imparted to the one or the other by means of a milled head placed on the right of the observer, which leaves a pinion working in a rack to which the

part to be moved is attached. By turning this milled head one way and the other alternately, the observer finds by trial the position which gives greatest distinctness.

33. This, which is called the COARSE ADJUSTMENT, answers well enough when high powers are not used; but it must be remembered that as the teeth of the pinion successively pass those of the rack, the motion produced is not strictly an even and uniform one, but a sort of starting or intermitting motion, so that the instrument cannot be easily and steadily brought to rest at any intermediate point between the beginning and the end of the passage of a tooth. When high powers are used, and consequently an extremely nice adjustment of the focus required, this arrangement is therefore insufficient, and serves at best only for a first approximation to the exact focus.

34. A supplemental expedient is therefore provided in the best instruments, called the FINE ADJUSIMENT, which usually consists of a screw having an extremely fine thread, which being connected with the part to be moved, gives it a perfectly smooth, uniform, and slow motion, entirely free from starts or jerks.

In some of the best instruments these screws have as many as 150 threads to the inch, so that one complete turn of the milled head moves the stage or body through only the 150th part of an inch, and as the head is divided into ten equal parts and moves under an index, a tenth of a revolution can be observed, which corresponds to the 1500th part of an inch.

When the form of the object is not actually flat, and consequently all points upon it are not equally distant from the object-glass, they will not be all in focus together. When the distance of the object is such as to bring the more salient, and consequently the nearest, parts into focus, the more depressed parts will be too distant and consequently out of focus; and when the object is moved nearer to the object-glass by a space equal to the heights of the salient above the depressed parts, the latter will be in, and the former out of focus, and consequently the latter will be distinct, and the former confused.

When the powers used are so low that the distance of the object from the object-piece shall bear a considerable proportion to the difference of level of the salient and depressed parts of the object, this difference of level will not sensibly affect the focal adjustment; but when high powers are used, that difference of level bearing a very sensible proportion to the distance of the object from the object-glass, the adjustment which renders either distinct will render the other indistinct.

35. This optical fact has been converted with admirable address

into an expedient, by which the inequalities of the surface of a microscopic object are gauged, and its accidents analysed. Thus, for example, let the milled head of the fine adjustment be first turned so as to render the salient parts distinct, and let the position of the index be marked. Let it be then turned so as to render the depressed parts distinct, and let the new position of the index be marked. If one division of the head represent the 1500th part of an inch, the differences of level, of the salient and oppressed parts, will be just so many 1500ths of an inch as there are divisions of the milled head which have passed the index.

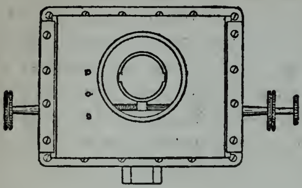
36. One of the first difficulties which the microscopic debutant encounters, is that which will attend his attempts to bring the object into the centre of the field of view when it is minute, and when the magnifying power is considerable. If he is only provided with a simple stage, without any mechanical expedient for moving the object, he will soon be oppressed with the fatigue arising from a succession of abortive attempts at accomplishing his purpose.

37. The entire diameter of the field of view will often be less than the 100th of an inch, so that a displacement of the slide so inconsiderable as to be utterly insensible to his fingers, will cause the object to jerk through a space greatly exceeding the entire extent of the field. In this way the object will start from side to side, the motion imparted to it by the touch to bring it back to the field being always in excess, however carefully and delicately the manipulation may be made. Some professional observers, by intense and long-continued practice, surmount this difficulty and succeed in adjusting the slides, even with the highest powers, without mechanical aid; but this is not to be hoped for by debutants or amateurs, except with very low magnifying powers. Such persons, if they would avoid the risk of throwing up the instrument with disgust, had therefore better in all cases be provided with a stage having some such expedients as we shall now describe.

Upon the fixed stage, such as it has been described, a second stage similar in form and equal in size is placed, and is moveable through a certain limited space right and left, by a fine screw with a milled head. Another similar stage is placed upon this, which partakes of any motion imparted to the latter, but which is also moveable upon the latter backwards and forwards by means of another fine screw. Upon this last stage the slide with the object is placed, and held down by springs so as to retain its place, whatever be the position of the stage.

By turning one of these screws (fig. 19), the object may be slowly moved right and left, and by turning the other it may be moved backwards and forwards, and, in fine, by turning both at the same time it may be moved diagonally in any intermediate direction, according to the relative rate at which the one and the other milled head is turned. Sometimes the two milled heads are on the right side of the stage, so that they can be turned either separately or together by the right hand, and sometimes they are placed at opposite sides, so as to engage both hands.

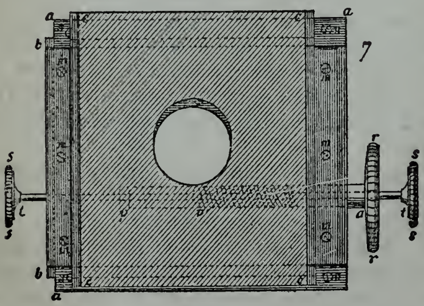
Fig. 19.



38. It is generally found convenient to have an easy means of turning the object round its centre, so as to present it to the light in all possible positions, without displacing it from the centre of the field. This is accomplished by inserting in the upper plate of the stage a metallic disc of somewhat greater diameter than the central aperture of the stage, which is so fixed as to be turned smoothly round its centre. It is upon this disc that the slide is placed and held by the springs which are attached to the disc so as to turn with it. This disc is sometimes graduated in 360°, so that the observer can turn the object through any desired angle, a power which will be found very convenient in certain classes of observations.

The arrangement consisting of a fixed with two moveable stages superposed is drawn in fig. 20, where *a a a a* is the fixed stage, and *b b b b*, *c c c c* the two stages which move in the grooves *n n* and *m m*, the one *b b b b* directed right and left, and the other *c c c c* backwards and forwards. The grooves in which the upper stage *c c c c* moves are formed in the lower stage *b b b b*, and those in which the latter moves are formed in the fixed stage *a a a a*. The one stage is moved by turning the milled heads *s s* fixed upon the

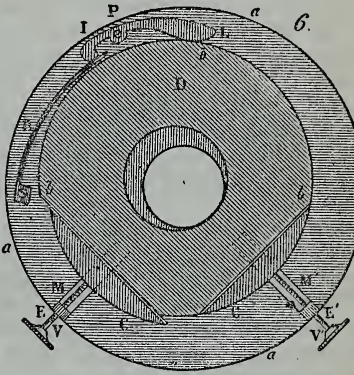
Fig. 20.



rod $t\,t$, and the other by turning the head $r\,r$ fixed upon the hollow rod v, through which $t\,t$ passes.

Another and more simple form of moveable stage is shown in fig. 21, where $a\ a\ a$ represents a circular brass disc, having a circular aperture in its centre. Upon this a second disc $b\ b\ b$ is placed, which is moved within certain limits in two directions, at right angles to each other, by the screws V V′, against which the spring R I P L reacts. The entire stage is in this case moveable round its own centre.

Fig. 21.



By these expedients the observer has complete command over the object, so as to be able to move it at pleasure in any direction, with a motion which will be smooth, slow, and free from jerks and starts, even when magnified with the highest powers.

To centre the object, that is, to place it on the stage so that its centre shall be in the centre of the field, is not so easy as it might appear to the unpractised in microscopic manipulation. To accomplish this, let the slide be first laid across the aperture of the stage, the object being as nearly as possible concentric with the aperture. Let the stage and object-glass be brought nearly, but not actually, into contact by the coarse adjustment. Let the slide be then again centred, so as to render the object concentric with the object-glass. Let the stage be then moved from the object-glass until the instrument is focussed as nearly as it can be by the coarse adjustment. Let the object be then more exactly centred by the stage-screws, and more exactly focussed by the fine adjustment.

It must not, however, be supposed that this elaborate process is necessary in the case of every class of objects. The larger sort can be easily enough centred by the hand, and focussed by the coarse adjustment; and in the cheaper description of microscopes no other means are provided. For a smaller sort, the centring may be effected by proximity with the object-glass, and rendered more exact with the fingers when no stage-screws are provided.

But much trouble will be produced when objects of the smallest class requiring the higher powers are examined with instruments in which the stage-screws and fine adjustments are not supplied.

39. In all cases it will be found advantageous to submit the object successively to a series of increasing powers. When once centred it will maintain its place while the object-lenses are changed, so that upon each change of power no new adjustment is necessary except focussing. The low powers will show the general form and contour, the entire object being at one and the same moment within the field. The next powers will show the larger parts, and the highest will display the texture of the surface and the structure of the smaller parts. By working the stage-screws the object is moved like a panorama across the field from right to left; and this motion is repeated for various positions given to it by the screws, which move it backward and forward until every part of it has been submitted to examination.

When high powers are used the object will be very close to the object-glass, so as almost to touch it when the instrument is focussed. In this case, care should be taken to prevent all contact or friction of the object or the slide with the object-glass, the latter being subject from that cause to injury or fracture. When it is desired therefore to change an object thus viewed with a high power, it is always advisable to separate the object-glass and stage by the coarse adjustment, before removing the one object and replacing it with the other, which must then be focussed.

40. The greatest care should be taken to clean the slides before placing them on the stage, since the least particle of grease or dust or any other foreign matter would, when magnified, injure the observation and might lead to errors.

When the object observed is in a drop of water or other liquid, or when it is itself a liquid, it will be included between the slide and a thin glass placed upon it, in which case it is of the greatest importance to exclude or remove all bubbles of air, since they would present appearances under the microscope, such as would deface those of the proper object of observation.

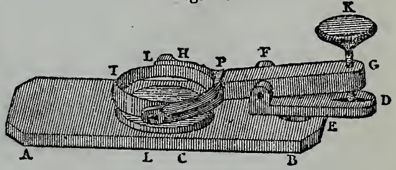
41. When it is required to submit a minute object to inspection, it is sometimes desirable to submit it to pressure, either to retain it in one position, if it be living, or to ascertain the effect of compression upon it, exercised in a greater or less degree for other purposes. It is often necessary also to roll it over, so as to present all sides of it in succession to the observer.

An instrument called a *compressor* has been contrived for this purpose, which has been constructed in a great variety of forms by different makers, according to the demands of different observers.

One of the most common and useful forms of compressor is shown in fig. 22.

A small and very thin disc of glass is set in a brass ring I, and supported at two points L L, diametrically opposite, by the ends of a fork L P, attached to a lever P G, the latter being supported upon two upright pieces F, attached to an horizontal piece F D. This piece F D turns horizontally round a pivot, fixed near the end E of a strong slip of brass A B, having the form and magnitude of a slide used for the support of objects. At the middle C, of A B, is a circular hole, in which another disc of glass is set, corresponding in magnitude to the disc I. A screw, with a milled head K, works in the end G of the lever, by turning which in one way or the other, the end G, and consequently the disc I, is raised or depressed.

Fig. 22.



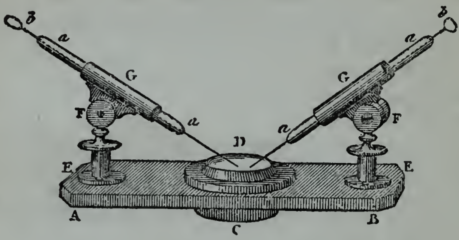
To place the object for observation, by moving the piece D round the pivot the ring I is removed from the lower disc C, upon which the object is then deposited. The screw K being turned, so as to raise the disc I sufficiently to prevent it from touching the object, the piece D is then turned on the pivot until the disc I is brought over the object. The observer then viewing the object in the microscope, and placing his hand upon the screw K, slowly turns it, so as gradually to compress the object, and continues this process or suspends it, or turns the disc I horizontally, so as to roll the object between the glasses, according as his course of observation may require.

The compression may be so increased as to flatten the object, which in some cases is desired, so as to render it more transparent, while nevertheless its form becomes more or less distorted.

42. It is sometimes required to ascertain the effects of an electric spark or voltaic current, transmitted through a liquid or solid, or through a body animate or inanimate. An apparatus adapted for this purpose is shown in fig. 23, where D C is a disc of glass set in the middle of a slip of brass A B. The two brass tubes G G play upon the hinges F F, which are supported on short glass pillars E E. Two glass tubes, through the bores of which fine platinum wires *a a* pass, are inserted tightly into the tubes G G, so that they can be pushed to, or drawn from the disc D,

where the object is placed. The positive and negative ends of the conductor of the electric machine, or the poles of a voltaic battery, being put in connection with the handles *b b* of the

Fig. 23.



platinum wire, the spark or current will pass from the point of one of the wires *a a* to that of the other, being transmitted through the object placed between them.

THE ILLUMINATION OF OBJECTS.

43. Among the accessories of the microscope, there is none the right use of which is more important than the illuminators. By the proper application of these, an infinite variety of beautiful effects are produced, and an infinite number of interesting consequences developed, while by their abuse, and by the misconception and misinterpretation of their indications, the most fatal errors and illusions may arise.

Let any one, however inexperienced in the manipulations of a microscope, applying one hand to the mirror and the other to the disc of diaphragms, vary at pleasure the position of the former, and turn the latter slowly round its centre, thus shifting the direction, and varying the quantity of the light which falls upon the object, and he will witness, in looking at the object through the instrument, a series of appearances which will soon demonstrate to him how curious, complicated, and important a part the illuminators play in microscopical phenomena.

44. Objects may be rendered visible in two ways, either by light reflected from those parts of their surfaces which are presented towards the observer, or by light falling on the posterior surface, and partially transmitted through them. Opaque bodies can be seen only in the former way, but translucent objects may be seen in either of these ways.

A translucent object presents a different appearance, according as it is seen by a front or back light. The leaf of a tree or plant, seen by reflected light, appears to have some particular tint of green, showing faint traces of a certain reticulated skeleton of vegetable fibre. If it be held up before the sun, all light being excluded from the side presented to the eye, it will appear with a much paler tint of green, and the skeleton will become much more visible, the finer parts before invisible being distinctly seen.

A stained glass-window viewed from the outside appears to have dark and dull colours, and might be taken to be opaque, showing no form or design. Viewed from the inside, forms of great beauty, and colours of remarkable splendour, are seen.

When we say, therefore, that objects viewed in a microscope present very different appearances, according as they are illuminated by a front or a back light, we only state a general fact common to all visible objects.

No body can be said to be either opaque or transparent in an absolute sense. Bodies considered to be the most opaque, such as the metals, are found to be translucent when reduced to thin leaves. Even gold and platinum, the most dense of the metals, are rendered translucent under the hammer of the gold-beater, while glass, diamond, air, water, and similar bodies, commonly considered to be transparent, are proved to absorb a portion of the light transmitted through them, this absorption increasing with the thickness of the medium. There is in fine no body which will not become opaque if sufficiently thick, and none that will not become more or less translucent if sufficiently thin.

45. Since microscopic objects are generally of extremely minute dimensions, they are all, with some few exceptions, sufficiently translucent to be rendered visible by a back light.

It is well known that many bodies, which are opaque or nearly so, may be rendered translucent by saturating them with certain liquids. Thus, as every one knows, paper, linen, and other porous bodies, which when dry are imperfectly translucent, become much more so when wetted or oiled, or saturated with white wax.

This general physical fact has special and important application in the preparation of microscopic objects, which are saturated with various liquids, proper for each of them, by which they are rendered translucent.

When a translucent object is rendered visible by a back light, the intensity of the light must be regulated according to its translucency. The more translucent it is, the less intense must be the light. A strong back light thrown upon a very translucent object drowns it, and renders it altogether invisible. The light must therefore be reduced in intensity by varying the inclination of the reflector, the distance of the lamp from it, and by the interposition of smaller diaphragms, until the best effect is produced. The observer will acquire by practice a facility in making these adjustments, so as to produce the desired result.

On the other hand, if the object be very imperfectly translucent, the light thrown upon it must be rendered as intense as possible by the contrary arrangements.

46. Different parts of the same object will generally have different degrees of translucency, and it will often happen that a light which would drown the more transparent parts will be no more than sufficient to display the more opaque parts. In such cases the observer will have to vary the light according as his attention is directed to one part or the other.

It must not be inferred that the darker parts are in this case really darker than those which are more transparent. The lesser degree of translucency more frequently arises from the different thickness of different parts of the object, the thicker parts absorbing more light, and therefore appearing of a darker tint than the thinner. If the varying transparency arise from this cause, the apparent lights and shadows or tints of colour must be taken as mere indications of the inequalities of thickness of a body of which the real colour is uniform.

The difficulty which an observer encounters in ascertaining the real form of an object, and the accidents of its surface when seen in a microscope by a back light, is partly owing to the fact that the eye is habituated to view objects almost exclusively by front lights, and the impressions produced of their forms are always deductions of which we are rendered unconscious by habit, by which the characters of these surfaces are inferred from the lights and shadows which are impressed on the organ of vision. Not having the same habit of seeing objects by a back light we cannot so easily make similar deductions, and we are apt to judge of the objects as if in fact they were illuminated with a front light.

The judgment is also more or less perplexed, and deceived by the fact that microscopic objects are as it were placed before the eye in an unnatural state of proximity, which give them a visual character totally different from that which objects have, viewed in the usual way with the naked eye.

It must be evident, therefore, how much attention and address on the part of the observer are indispensable to enable him to disentangle their physical causes from such complicated effects, and to give their appearances a right interpretation.

47. If an object, of which the surface is marked by numerous inequalities and asperities, be illuminated by a light which falls perpendicularly upon it, or which is scattered indifferently in all directions, an observer placed directly over it will be in general

unable to perceive the elevations or depressions, all being projected upon the same ground-plan, and all being similarly illuminated. But if the light fall upon it with a certain and regular obliquity, lights and shadows will be produced which will enable him to infer the accidents of the surface and the real form of the object.

The due consideration and application of this general optical fact will enable the microscopic observer to submit the object of his inquiry to such a visual analysis as will unfold at least a close approximation to its real form.

48. If the object be viewed by a front light proceeding from the concave mirror M M, fig. 13, or reflected by the Lieberkuhn, this effect will not be produced; for although the light reflected from the Lieberkuhn is not perpendicular to the object, it is scattered in all possible directions, so as utterly to remove all possibility of lights and shadows. An expedient is sometimes adopted in which light projected by a concave mirror or lens, properly placed, is directed only on one side of the Lieberkuhn, which is necessarily productive of lights and shadows.

But the purpose is much more simply and effectually attained by removing the Lieberkuhn altogether, and directing the illumination with the necessary obliquity upon the object by means of a reflector or lens placed as shown at M′ M′ or L L.

Those methods are always practicable except when a magnifying power is used so high as to render it necessary to bring the object almost into contact with the object-glass, in which case the mounting of the latter would intercept the light, whether proceeding from the Lieberkuhn, the lens, or mirror. In such cases the object can only be illuminated by a back light.

If the object be illuminated by a back light thrown obliquely upon it, the lights and shadows, strictly speaking, can only be produced upon the posterior surface. Nevertheless, the light passing obliquely through the anterior surface will produce dark and light tints, according to the angle at which it strikes the several superficial inequalities and accidents of that side of the object. It will be evident, therefore, that very complicated effects, in which the disentanglement of the forms which produce them is extremely difficult, must ensue.

Nevertheless, the attentive and practised observer, by presenting the illumination successively in various directions, by properly varying its intensity, and examining the object as well by front as by back illumination, when both are practicable, can generally arrive at a pretty clear knowledge of its form and parts.

49. When the object is illuminated by a back light, optical phenomena, called diffraction and interference, are produced,

against which the observer must be on his guard. The effects of these are to surround the outline of the object with coloured fringes. By limiting the illumination as far as it is practicable to the object itself, so as to avoid the transmission of any light through the opening of the slide, except what may pass through the object, this effect may be diminished or avoided.

Indeed, for many reasons, it is advantageous to prevent any light from passing through the slide, or through the opening of the stage, except what is employed in illuminating the object. All such light is liable to fall in greater or less quantity upon the object-glass, and, passing through it, has a tendency to render the image obscure and confused. For this reason, all extraneous light whatever should be as far as possible excluded from the space around the microscope, for all objects on which such light falls will reflect a part of it, some of which may fall upon the object-glass.

50. When the light of the sky or clouds is used, an aperture may be made in a window-shutter for its admission, all the other windows of the room being closed, and the light proceeding from the aperture being received upon the mirror or lens, by which it is directed and condensed upon the object. The light of a white cloud, strongly illuminated by the sun, is generally considered the best form of day-light which can be used, and that of a blue serene sky the worst. Observers differ as to the direct light of the sun, some maintaining that in no case whatever should it be used, while others give it a preference for minute objects seen under high powers, and therefore requiring intense illumination.

The light reflected from a white wall upon which the sun shines is a good source of illumination.

51. If artificial light be used with low powers, a common sperm candle will serve well enough, but means should be adopted to prevent the flickering of the flame.

An argand lamp, however, is, in all cases, preferable, as giving a steady invariable light. It will be improved if good olive oil be used instead of the fish oil.

The flame produced by the liquid known as camphine is especially pure and white, and well fitted for microscopic researches.

Whatever be the artificial light used, it ought to be surrounded with a shade, and so placed as to fall only upon the mirror or lens by which it is directed to and condensed upon the object.

52. It is advantageous to protect the eyes of the observer from extraneous light: the most simple and convenient method of effecting which is by a circular blackened pasteboard screen

about a foot in diameter, having a hole in its centre, through which the tube of the eye-piece is passed. This screen is then at right angles to the axis of the body of the instrument, the eye-piece projecting about an inch from it. The observer looking into the eye-glass with one eye, need not incur the exertion and fatigue of closing the other, since the screen performs the office of the eye-lid.

The mirrors are sometimes made with a concave glass at one side, and a plane glass at the other, the latter being used when condensation is not required. A disc formed of plaster of Paris, reduced to an extremely even and smooth surface, either plane or concave, is sometimes used with advantage when a soft and mild light is required. Nearly the same effect may be produced by placing a disc of white card upon the face of the mirror. The illumination by a back light is attended with a peculiar advantage, inasmuch as it displays the internal structure of objects, and, in the case of organised bodies, supplies beautiful means of exhibiting the circulation; as, for example, the circulation of the blood in animals, and the sap in vegetables. In the case of certain animalcules, it shows some living and moving within the bodies of others.

53. The following observations of Mr. Pritchard are worthy of attention:—" We must consider that in all bodies viewed by intercepted light, there is, properly speaking, neither light nor shade, in the ordinary acceptation of these terms; there are only dark and light parts, which again assume new aspects as the light is more or less direct or oblique. Thus depressions on transparent objects are almost sure, under the action of oblique light, to assume the effect of prominences; but prominences seldom or never have the semblance of depression. As almost all diaphanous bodies can be examined as opaque objects, a scrutiny of them in this way will generally be found greatly to assist our judgment concerning their nature, whether they admit of being cut into sections or not. It would be easy to write a volume on this subject only, if we commenced an illustration of particulars which could not be rendered clear and satisfactory without a vast number of figures. Long practice must, after all, determine our opinions, and scepticism should ever form a leading feature in them; we should *suspect rather than believe.*

" Opaque objects are not, upon the whole, so liable to produce optical deceptions as transparent ones, because we are more in the habit of viewing ordinary bodies by reflected or radiated light. The most common illusion presented by them is that of showing a *basso-relievo* as an *alto-relievo ;* the reverse deception sometimes occurs also, but more rarely. This effect occurs in ordinary objects viewed by the naked eyes, as well as in microscopes, especially if but one eye is employed. Thus, if we look intently for some time at a basso-relievo (a die of a coin, for example), *illuminated with very oblique light*, it at first appears in its true character; but, after a little while, some point on which we more particularly direct our gaze will begin to appear in *alt*, the whole rapidly follows; in a little time the effect wears off, and we again see it in bas-relief; then again in alt; and so on, by successive fits. This deception arises from the simple circumstance that *the lights and shades in bas-relief are very nearly like those of an alto-relievo of the same subject, illuminated from the opposite side;* our understanding in this case instantly corrects the false testimony of the eye, when we *consider from which side the light comes.* (If we observe with a microscope, we must remember that its image is inverted, and that in consequence the light must be considered as proceeding from the side of the field of view opposite to that where the source of illumination actually exists.) It will also be highly advisable, when we are in doubt as to the manner in which an instrument shows prominences and depressions, to verify its vision by observing some *known object* with it, of the real state of which, as to inequality of surface, we have been previously informed by the sense of touch, to which it has been well said there is no fellow." *

* "We usually see objects illuminated from *above* with the *shadows below* the prominences; now, unless the light is below an opaque object, when we view it in an engiscope, we shall see the *shadows above*, giving the prominences the appearance of depressions, and producing a very unnatural effect."

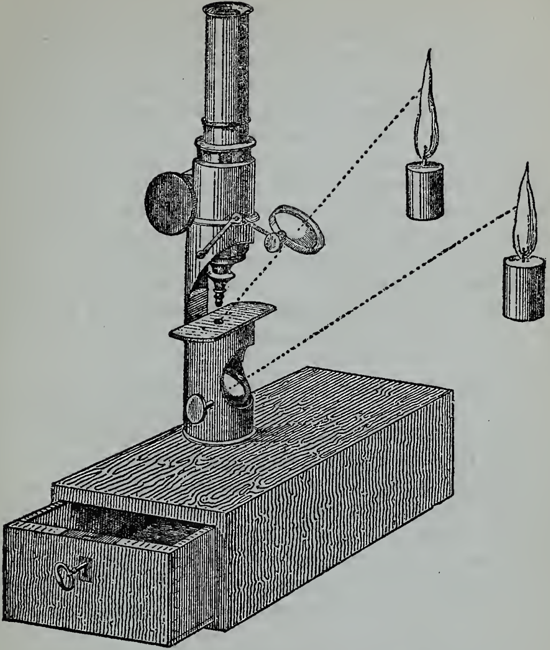


Fig. 36.—Frauenhoffer's Microscope.

THE MICROSCOPE.

CHAPTER IV.

Pritchard's analysis of the effects of illumination (continued). Measurement of objects: 54. Measurement distinct from magnifying power.—55. Measurement by comparison with a known object.—56. Micrometric scales.—57. Thin glass plates.—58. Micrometers.—59. Le Baillif's micrometer.—60. Jackson's micrometer.—61. Measurement by the camera lucida.—62. Goniometers. Magnifying Power: 63. This term much misunderstood.—64. Its exact meaning.—65. Least distance of distinct vision.—66. Visual estimate of angular magnitude.—67. Method of determining magnifying power by the camera lucida.—68. Dimensions of the least object which a given power can render visible.

"ILLUMINATION, by cups or silver specula, does not produce these illusions, because they create no shade—the whole object is one mass of intense light; other false perceptions are, however, occasioned by them. Thus, all globular bodies, having polished surfaces, reflect an image of the cups, and the *spout*, if there is one, appears as a dark spot in the centre. The eyes of insects, illuminated in this way, show the semblance of a pupil in the centre of each lens, which deception may be verified by examining small globules of mercury in the same manner. Spherical bodies, with bright surfaces, will even, on some occasions, reflect an image of the object-glass and its setting, on the same principle; so that we must perpetually consider the laws of the refraction and reflection of light, in all the conclusions we draw from the evidence even of the very best instruments, used with every possible precaution.

"Lastly, it must be observed, that in using microscopes, we must never attempt to verify an object concerning which we are uncertain, by increasing the depth of the eye-glass immoderately, so as in this way to obtain a very high power. A negative eye-glass, of about one-fourth of an inch focus, is the deepest which should ever be employed, even with a short body; for a microscope only shows a *picture* of an object, and the more it is amplified the more its imperfections are developed. It is, on this account, much safer to trust to moderate powers in these instruments, in preference to high ones, *unless they are obtained through the medium of the depth and power of their objective part.* It is the nature of deep eye-pieces to cause all luminous points to swell out into discs, and to render the image soft, diluted, and nebulous, at length all certain vision fades away, and the imagination is left to its uncontrolled operation. Single and compound magnifiers, having to deal with the real object, may be made of any power which can be used; and if our eyes are strong, and habituated to their use, we may place great reliance on their testimony; but we must never allow them to persuade us to believe marvels which are manifestly impossible, or contrary to the known laws of nature and right reason."

MEASUREMENT OF OBJECTS.

54. The determination of the real magnitude of microscopic objects, and that of the magnifying power of the instrument, are problems closely connected but not identical. Either may be solved independently of the other.

55. If two objects be placed at the same time within the field of view, the real magnitude of one of which is known, that of the other may be at least approximately estimated by comparison.

Since they are equally magnified, their real will be in the proportion of their apparent magnitudes. If, therefore, they appear equal, they will be equal, and if that which we desire to measure appear to be twice or half the size of that whose magnitude we know, its real magnitude will be twice or half that of the latter.

Such was the micrometric method used by the earlier observers. Thus Lewenhoeck procured a number of minute grains of sand, sensibly equal in magnitude, and placing as many of them in a line, and in contact, as extended over the length of an inch, he ascertained the fraction of an inch, which expressed the diameter of each. When he desired to ascertain the actual magnitude of an object seen with his microscope, he placed one of these grains beside it, and estimated by comparison the magnitude of the former.

Various natural objects, whose magnitudes are known, and which are subject to no perceptible variations, such as the sporules of Lycoperdon bcvista or puff-ball, whose diameter is the 8500th of an inch, those of the lycopodium, which measures the 940th of an inch, and others such as hair, the filaments of silk, flax, and cotton, and the globules of blood, have been suggested as standard measures to be similarly used.

More modern observers, adhering to the same method, have substituted artificial for natural standards. Thus extremely fine wire, called micrometric wire, has been used. This wire can be drawn with an astonishing degree of fineness. Dr. Wollaston invented a process by which platinum wire was produced, whose thickness was only the 30000th part of an inch.*

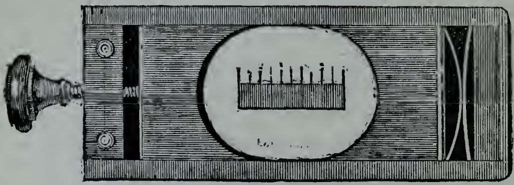
56. Such measurements are now more generally made by means of a minute scale engraved on glass, with a diamond point. Let us suppose, for example, a line, the 20th of an inch in length, traced across the centre of a glass disc, set in a thin brass plate of the size and form of the sliders on which objects are mounted. Let this line be divided into 100 equal parts, every fifth division being distinguished by a longer line, and every tenth by a still longer one. Each of these divisions will be the 2000th part, the intervals between the fifth divisions will be 400th, and that between the tenth divisions the 200th part of an inch. This microscopic scale will be seen magnified with the microscope, and any microscopic object laid upon it will be seen equally magnified, so that its dimensions can be ascertained by merely counting the divisions of the scale included between those which mark its limits when placed in different positions on the scale.

It may perhaps be thought impracticable to make divisions so

* Handbook of Natural Philosophy, 2d edition, Mechanics, 38.

minute upon the glass, with the necessary precision, especially when it is remembered that any error or inequality will necessarily be augmented in the exact proportion of the magnifying power with which such a scale is seen. Nevertheless this difficulty has been most successfully overcome, and combinations of screws and

Fig. 24.



wheels have been contrived, by which the diamond point is moved by self-acting mechanism, so as to trace the successive divisions of scales of astonishing minuteness. Scales are thus produced, the divisions of which are no greater than the 25000th part of an inch.

This extreme minuteness is, however, rarely necessary or desirable in microscopic researches, and the divisions of the scales in more common use vary from the 1000th to the 2000th of an inch. In the scales delivered with moderately good French instruments, a millimetre is divided into one hundred parts. A millimetre being about the 25th of an inch, these divisions would therefore be the 2500th of an inch. (See Tract on Microscopic Drawing and Engraving, Museum, vol. vi.)

The process described above, in which the object is measured by superposition upon the micrometric scale, is attended with several practical difficulties and objections. The object, when thus placed, is always nearer to the object-glass than the scale, and when it is in focus, the scale is out of focus and invisible; and, on the other hand, when the scale is in focus, the object is out of focus and indistinct. When low powers only are used, this difference between the focus of the object and that of the scale being inconsiderable, will not prevent the success of the operation; but when the powers are high, it can never be satisfactorily, and sometimes not at all effected.

There is still another objection to the process. The placing and displacing of objects frequently on a surface so delicately engraved, subjects it to friction, which soon spoils and effaces the divisions.

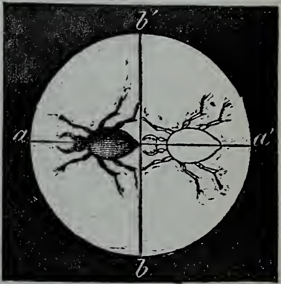
If the divided surface be protected, as it may be, by a plate of glass laid upon it, the difference between the distances of the object and the scale from the object-glass is augmented by the thickness of the glass which covers the scale; and however thin this glass may be, where high powers are used, it will render the difference of the foci of the scale and the object so sensible, that they can never be both seen with sufficient distinctness at the same time.

57. We know no greater example of the inexhaustible resources of art, and the untiring zeal with which its cultivators minister to the wants of science, than the wonderful perfection to which the mechanical division of a material so fragile as glass has been carried. For the reasons we have here stated, as well as because in the application of the highest magnifying powers the object-glass of a microscope requires to be almost in contact with the object, without actually touching it, microscopists required extremely thin plates of glass to cover delicate objects mounted on their slides. Messrs. Chance of Birmingham responded to this demand by the production of plates of glass so thin, that three hundred of them piled one upon the other are no higher than an inch.

For examples still more striking of the minuteness with which lines may be traced upon glass by mere mechanical processes, we may refer the reader to that part of our Tract upon Microscopic Drawing and Engraving, in which the test plates of Mr. Nobert are described.

58. One of the most evident expedients for the measurement of microscopic objects would seem to be the micrometer screw, which is applied with so much success, and with results of such extreme precision, in astronomical instruments. Various methods of applying it to the microscope will suggest themselves to every one who is familiar with its uses in the observatory. Let two filaments of spider's web, or micrometric wire, be extended at right angles across the field in the focus of the eye-piece. These will divide the field horizontally and vertically at right angles, intersecting at its centre, as shown in fig. 25. Now suppose the stage supporting the object is capable of being moved by a micrometer screw, having for example one hundred threads to the inch. Let the object be placed first so that its length shall be horizontal, and let the slip be adjusted so that the vertical micrometric wire *b b'* shall coincide with one of its extremities. Let the micrometer screw be now turned so that the object shall move horizon-

Fig. 25.



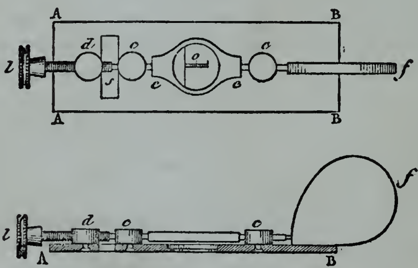
tally. It will appear to pass gradually under the vertical wire until its other extremity shall coincide with that wire. If then the number of complete turns, and parts of a turn of the screw be counted, the length of the object then will be known. Thus, if at the end of every complete turn, the screw produce an audible sound like the tick of a clock, the observer can count the complete turns, and if the circumference of the head be divided into 100 parts, and that an index be fixed upon the stage to indicate the position of the head at the commencement, the decimal parts of a turn can be ascertained, each division of the head corresponding to the 100th part of a complete turn, and therefore to the 10000th of an inch.

By turning the stage so that the screw will cause the object to move across the field in the direction of the vertical wire, its dimensions in the other direction can be ascertained.

59. A simple and ingenious micrometer for ascertaining the dimensions of such objects as would bear a slight pressure without change of form, was invented by M. Le Baillif. A plan and vertical section or side view of this are shown in fig. 26.

Two upright pieces, *c c*, are fixed in a slip of copper, formed like one of the slides, having a circular hole in its centre, in

Fig. 26.



which is set a plate of glass, on which a scale *o* is engraved. Upon this is placed a moveable piece, *e e*, having a similar hole and plate of glass, with a fine line engraved upon it at right angles to the scale, so that when it is moved from left to right this fine line will coincide necessarily with all the divisions of the scale. From this piece, two rods proceed, which pass through holes in the upright pieces *c c*, and one of them is reacted upon by a piece of watch-spring, *f*, while the other abuts against the end of a fine screw, *l*, which moves in a nut, *d*.

When an object is to be measured, the index line upon the upper glass disc is brought to coincide with the first division or zero of the scale by turning the head *l* so as to cause the screw to retire from the piece *e e*, the spring *f* then pressing this piece towards the screw. The object to be measured is then inserted between the end of the rod projecting from *e* and the screw, and consequently the piece *e e* and the index line engraved upon it will be pushed from left to right through a space equal to the thickness of the object. This thickness may then be ascertained by observing with the microscope the division of the scale to which the indicating line has been advanced.

60. A micrometer, having some resemblance to this, but made more applicable to the general purposes of microscopic measurement, has lately been contrived by Mr. Jackson, a description of which is published in the "Transactions of the Microscopical Society."

A disc of glass, upon which a micrometric scale is engraved, is set in a thin plate of brass, which moves with a sliding motion on another plate, in which a corresponding hole is made. The former is like that of M. Le Baillif, urged by a fine screw in one direction, and driven back by a spring in the other, as shown in fig. 24.

Fig. 27.

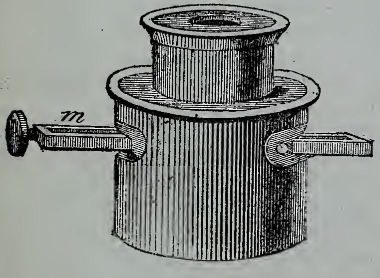
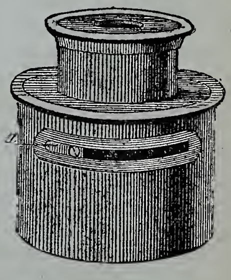


Fig. 28.



This micrometer slide is inserted in the tube of the eye-piece by openings in the sides of the tube, as shown at *m* in fig. 27, which openings can be closed when the micrometer is not used by sliding covers, as shown at *a*, fig. 28.

It is easy to see how this contrivance is applied. The scales magnified by the eye-glass are projected upon the optical image of the object produced by the object-glass, and this image may be made to move so as to bring its extremity to coincide with the first division of the scales. The scale will then show not only the dimensions of the entire object, but those of its parts. The object may be turned in any direction relatively to the scale that may be desired, by means either of the hand or the stage adjustments.

It is necessary, however, before applying this micrometer to the measurement of objects, to ascertain the value of the divisions of the scale relatively to the object, since the immediate subject of its measurement is, not the object itself, but the optical image of the object produced in the focus of the eye-piece by the object-glass; and this preliminary valuation is the more necessary, inasmuch as the relative magnitude of the image, compared with that of the object, will vary with the power of the object-piece.

To ascertain, then, the value of the divisions of the scale, let another micrometric scale, the divisions of which are known, be placed upon the stage. An image of this scale, magnified as that of an object would be, will then be formed in the focus of the eye-piece, and the other scale will be seen projected upon it. Let the position of the two scales be so adjusted by the stage arrangements that the first division of the one shall be projected on the first division of the other. By observing then the next divisions of the two which coincide, the relative value of the scales will be known. Thus if ten divisions of the eye-piece scale exactly cover 100 divisions of the other, and if each division of the latter be the 1000th of an inch, one division of the eye-piece scale will correspond to the 10000th part of an inch in the dimensions of an object.

It is evident that the value of the divisions of the scale should be determined for each object-piece which the observer uses.

61. The combination of the camera lucida with the micrometric scale has supplied a very simple and convenient method of measuring microscopic objects.

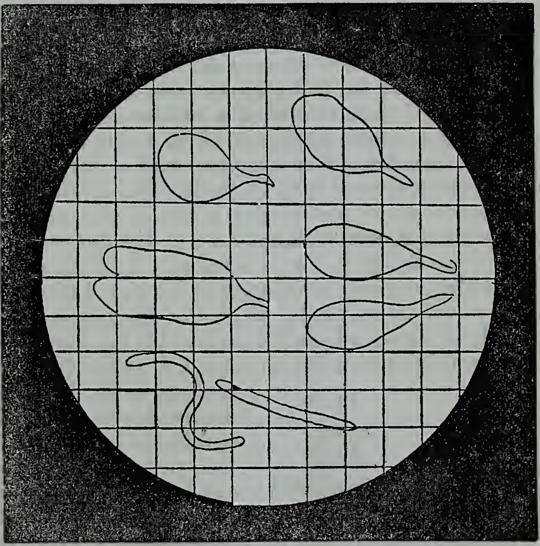
It has been shown in our Tract upon The Camera Lucida, that by that instrument the image of an object magnified in any desired proportion can be thrown upon a sheet of paper upon which its outline can be traced. The micrometric scale is first thus projected, and its divisions, or as many of them as are considered necessary, are traced upon the paper. Another similar series of divisions being traced at right angles to the former, the part of the paper corresponding to the field of view is divided into a system of squares, like those into which a map is divided by the lines of latitude and longitude. The micrometric slide being removed from the stage, the slide with the object is substituted for it, and the observer sees the image of the object similarly magnified projected upon the paper, already spaced out by the squares. He can therefore count the number of squares occupied by its length and breadth, and by the length and breadth of its several parts, or, better still, he can trace its outline upon the paper, so that its dimensions and those of all its parts can be exactly ascertained. Thus, if each division of the scale is the 1000th of an inch, the side of each square will represent the

1000th of an inch, and these sides may themselves be easily subdivided into ten or 100 parts, so as to carry the measurement to 10000ths or 100000ths of an inch.

In fig. 29 the field of view is represented spaced out in this manner, with the outlines of objects traced upon it.

Such a scale once drawn upon the paper, will serve for the measurement of any objects which may be submitted to the microscope; but it is most essential that in all such measurements the paper be kept at exactly the same distance from the camera, and that neither the object-glass, the eye-glass, nor the stage shall suffer any change in their relative positions.

Fig. 29.



It has been shown that the magnitude of the image received on the paper increases with the distance of the paper from the camera. If, therefore, the paper be placed at a greater or less distance from the camera to receive the image of the object than that at which it was placed to receive the image of the micrometric scale, the image of the object will be produced upon a scale greater or less than that on which the image of the micrometric scale was produced, and consequently the one cannot be taken as a measure of the other.

If any change be made in the relative positions of the eye-piece, object-piece, and stage, a corresponding change would be made in the magnifying power of the instrument, and a consequent change in the dimensions of the picture of any object projected by the camera on the paper, though no change be made in the distance of the paper from the camera.

In fine, the method of measuring the actual dimensions of a microscopic object by means of a scale drawn with the aid of the camera, requires that the instrument and the paper shall be in precisely the same state when the image of the object is projected on the paper as they were when the scale was drawn upon the paper.

If this condition be observed, measurements can be made by the camera with all the necessary facility and precision.

62. In microscopic researches it is frequently necessary to measure the angles at which the lines which form the contour of objects are inclined to each other. Various forms of *goniometers* * have been contrived for this purpose. One of the most simple and convenient of these consists of a circular plate of brass C C, fig. 30, having a central opening in which a disc of glass is set, on which a diameter *d b* is engraved with a diamond point. Upon this, and concentric with it, another similar plate, toothed at the edge, is placed, having also a disc of glass of the same magnitude set in it, with a diameter *a c* in like manner engraved upon it. Upon the plate C C an ear is cast, in which a pinion is inserted, which, working in the teeth of the second disc, gives it a motion round its centre, by which the diameter *a c* is made successively to assume all possible angles with the diameter *d b*.

This piece is inserted in the eye-piece A B, a side view of which is shown in fig. 31, so as to be concentric with the lenses, and to coincide with the focus of the eye-lens. The lines *a c* and *b d* will then be seen projected on the image of the object, and if the vertex of the angle it is desired to measure be brought, by means of the stage adjustments, to coincide with the centre O of the disc *a b c d*, where the two engraved diameters intersect, and so that one side of the angle to be measured shall coincide with the fixed line *d b*, the line *a c* can be turned by the pinion F, until it shall coincide with the other side. A graduated circle which surrounds the disc will then show the magnitude of the angle at which *b d* and *a c* are inclined.

Fig. 30.

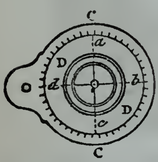
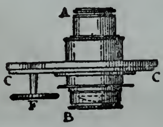


Fig. 31.



* From the Greek word γόνυ (*gonu*), knee.

THE MAGNIFYING POWER.

63. It has been well said, that a question clearly put is half resolved. There is no term in microscopic nomenclature so familiar to the ear, and so flippant on the tongue, as the "magnifying power;" yet there is none respecting which there prevail so much confusion and obscurity. The chief cause of this is the neglect of a clear and distinct definition of the term.

It has been already shown, that the magnitudes observed with the microscope are visual, not real. We can say that such or such an object seen in the microscope has a magnitude of so many degrees, but not at all one of so many inches. Strictly speaking, the same is true of all objects seen in the ordinary way; but in that case the mind is habituated to form an estimate of their real magnitudes, by combining the consideration of their apparent magnitudes with their distances. It is true that we are unconscious of the mental operation from which such estimates result, but it is not the less real. Our unconsciousness of it arises from the force of habit, and the great quickness of the acts of the mind. Every one who has been familiar with intellectual phenomena knows that such unconsciousness is found to attend all such acts as are thus habitual and rapid.

64. But when objects are looked at in a microscope, the mind not only does not possess the necessary data to form such an estimate, but the conditions under which the visual perceptions are formed are so unusual, and, so to speak, unnatural, that it is incapacitated to form an approximate estimate even of the visual, to say nothing of the real, magnitude of the object of its perception.

The visual magnitude of an object, as seen in a microscope, is the angle of divergence of lines supposed to be drawn from the eye to the limits of the imaginary image formed by the eye-glass, which is the immediate object of perception. When we say, therefore, that the instrument has such or such a magnifying power, every one will comprehend that it is meant that this visual magnitude is so many times greater than the visual magnitude which the object would have, if it were seen in the usual way without the interposition of any optical expedient.

So far all is clear, and so far there can be no difference of opinion on the point, provided only that the latter member of the sentence be clearly defined. What is the "visual magnitude *seen in the usual way?*" There are many ways of looking at an object, and "the usual way" depends much on the magnitude of the object. We can see well enough the dome of St. Paul's Cathedral at the distance of half a mile, while we cannot see a small insect at the distance of a yard. The same object may be viewed at different distances, and will have different visual magnitudes, these magnitudes being greater as the distance is less. The visual diameter of a small object, seen from the distance of a yard, is three times less than when seen from the distance of a foot. It appears, therefore, that the "visual magnitude of an object seen in the usual way with the naked eye," is a term of comparison which, without some further condition to limit it, has no fixed meaning, and consequently leaves the "magnifying power" of which it is made the standard, altogether vague and indefinite.

65. The visual magnitude therefore which is made the standard of magnifying power, must be the visual magnitude at some arbitrary distance conventionally assumed. As we have already stated, it has been generally agreed, since micrography has taken the rank of a special branch of science, to adopt ten inches as the standard distance. This distance is recommended not merely on account of the arithmetical facility which arises out of its decimal character, but because it agrees sufficiently for all practical purposes with the standard derived from the measures of other countries. In France, for example, the standard usually adopted is twenty-five centimètres, which is equal to 9·427 inches, being less than ten inches by only about the sixth of an inch.

According to this convention, then, the magnifying power of a microscope would be the number of times the visual diameter of the object viewed with the microscope is greater than its visual diameter viewed by an eye placed at ten inches from it. Thus, if the visual diameter of an object seen at the distance of ten inches be fifteen minutes of a degree, and the visual magnitude of the same object seen with a microscope be two and a half degrees, or 150 minutes, the magnifying power will be ten.

But an objection will even still be raised. The object may be so small that at the distance of ten inches it would not be visible at all with the naked eye. Nay, it may be, and in the case of microscopic objects often is, so minute that it would not be perceptible to the naked eye at any distance, however small. In that case it may be asked, What is to be understood by "its visual magnitude at the distance of 10 inches?"

This point will require some explanation. There is a certain limit of magnitude within which an object will cease to make any sensible impression of its magnitude or form upon the eye. This minor limit of magnitude varies with different individuals, and, in the case of the same individual, with different objects according to their colour, illumination, the ground on which they are projected, and many other conditions which it is not here necessary to discuss. It will suffice to say that there is such a limit. If the visual angle formed by lines diverging from the eye to the extremities of the object be within this limit, the object will not be perceived; or, to speak with more rigour, its magnitude and form will not be perceived.*

In such cases, therefore, the visual magnitude of an object, without the intervention of the microscope, must be understood to mean the angular divergence of the rays which would be drawn from a point placed at ten inches from the object to its extremities. This would be the visual magnitude of the object "*if it could be seen*" at that distance.

In fine, therefore, the definition of the magnifying power of a microscope will be clear, distinct, and adequate, if it be stated thus:—It is the quotient which would be obtained by dividing the visual magnitude of the object, as seen in the microscope, by the visual magnitude which the object would have to a naked eye placed at ten inches distance from it, supposing the eye to have sufficient sensibility to perceive it at that distance.

Every one is more or less familiar with real magnitude, so that when an object of ordinary dimensions is placed before them they can give at least a rough estimate of its actual dimensions. The same facility of estimating visual magnitude does not exist, although, in fact, we receive the impressions of visual much more frequently than those of real magnitude. The estimate of visual magnitude, however, enters into all microscopic inquiries as an element and condition of such importance, that all those who use the instrument, whether for the purposes of serious research or rational amusement and instruction, would do well to familiarise themselves with it. Some observations illustrative of such sensible impressions will therefore, we presume, be not unacceptable to our readers.

66. Our great familiarity with real magnitude arises from our intimate knowledge of certain standard units by which it is counted. There is no one, however little educated, that has not a pretty clear notion of the length expressed by an inch, a foot, and a yard. Let us see whether we may not enable any one with common attention to acquire an equally clear notion of the standard units of visual magnitude.

Every one is familiar with the apparent magnitude of the disc of the full moon. It is visible to the whole world, and seen for several nights in each month during the entire life of every individual. Now it happens that the visual magnitude of its diameter

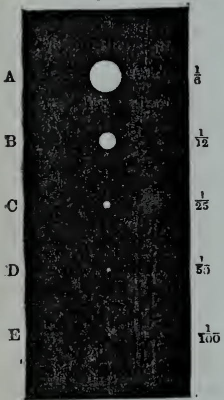
* The fixed stars are visible as mere luminous points, but their forms and magnitudes are not perceivable, owing to the extreme smallness of their visual angle produced by their enormous distances.

is just *half a degree*, which means, that the angular divergence of lines drawn from the eye to the extremities of the diameter is the same as that of two lines drawn from the centre of a circle to the extremities of an arc, which is the 720th part of the entire circle. Every one, therefore, who is familiar with the appearance of the full moon, will be as familiar with the meaning of a visual angle of half a degree, and, consequently, of a degree as they are with the real magnitude of an inch or a foot.

The distance of the moon has been ascertained to be 120 times its own diameter, and it is evident that any circular disc whatever, whose distance from the eye is 120 times its own diameter, will have a visual angle equal to the diameter of the moon, and therefore to half a degree; and, consequently, one whose distance is sixty * times its own diameter, would have a visual angle of a degree.

Thus, in fig. 32, there are five white discs shown upon a black ground: the diameter of the first is the 6th of an inch; that of the second, the 12th; that of the third, the 25th; the fourth, the 50th; and the fifth, the 100th. If these be held at ten inches from the eye, the first disc, A, will have a visual angle of 1°; the second, B, one of 30′; the third, C, about 15′; the fourth, D, $7\frac{1}{2}'$; and, in fine, the fifth, E, $3\frac{3}{4}'$.

Fig. 32.



It follows, therefore, that an object which when viewed with a magnifying power of 1000, appears with the same visual diameter as the moon, or as the disc B, fig. 32, placed at 10 inches from the eye, must have a real diameter no greater than the 12000th part of an inch.

Having familiarised himself with some such standards of visual magnitude as these, and once knowing the magnifying power of his instrument, an observer can easily make a rough estimate of the real magnitudes of the objects under view.

67. But for this, as well as many other purposes of microscopic research, it is necessary that the actual magnifying power of the instrument be ascertained.

The most simple and direct means of accomplishing this are supplied by the camera lucida.

* More strictly 57·3 times; but the round number will be sufficient for the above illustration.

Let a micrometric scale, such as we have already described, be placed on the stage, the instrument focussed, the camera attached, and a sheet of paper placed at 10 inches from it. An image of the scale being seen on the paper, let any two contiguous divisions of it be marked with the pencil. Let the distance between these marks be then exactly measured, and let it be divided by the actual length of the divisions of the scale. The quotient will be the magnifying power.

Thus, for example, let us suppose that the micrometric scale is the 25th part of an inch, and that this length is divided into 100 parts, each of these parts will be the 2500th part of an inch. Now suppose that it is found that the distance between the images of two contiguous divisions on the paper, is four-tenths of an inch. It will follow that the visual magnitude of a division of the scale is magnified in the proportion of $\frac{1}{2500}$ to $\frac{4}{10}$, that is, as 1 to 1000. The magnifying power would therefore be a thousand.

There are other methods of ascertaining the magnifying power, but this is so simple, so easily produced, and so precise, that we shall not detain the reader by any notice of others.

Microscopes being generally supplied with several object-glasses, and eye-pieces, the observer and amateur would do well once for all to ascertain the magnifying powers of all the possible combinations of them, and to tabulate it and keep it for reference.

68. It is often asked, What are the dimensions of the most minute object which a microscope, having a given magnifying power, is capable of rendering distinctly visible?

The answer to this question will depend on the answer to another; What are the least dimensions of the same object, with which it would be distinctly visible, at ten inches distance, with the naked eye?

Whatever be the latter dimensions, the former will be just so many times less as there are units in the number which expresses the magnifying power.

Thus, for example, if the smallest linear dimensions with which the object could be distinctly seen without a glass at 10 inches distance were the 300th part of an inch, a microscope having a magnifying power of 500 would render such an object equally visible if its linear dimensions were only the $300 \times 500 = 150000$th part of an inch.

It is generally considered that the smallest disc of which the form can be distinguished by the naked eye, being properly contrasted with the ground upon which it is seen, is one which would have a visual angle of one minute; and since a line measuring the 360th part of an inch, placed at ten inches distance, would have that visual angle, it would follow that the smallest object of which the form could be rendered distinctly visible by a microscope of a given magnifying power, would be one whose linear dimensions are as many times less than the 360th part of an inch as there are units in the number expressing the magnifying power.

It must not be forgotten, however, in considering such points, that the smallest object whose form can be distinctly seen at a given distance without a glass, depends on many conditions, some connected with the object, and some with the observer, as has been already stated.

Many persons fall into the error of supposing that the excellence of a microscope is to be determined by the greatness of its magnifying power. On the contrary, that instrument must be considered the most efficient which renders the details of an object perceptible with the lowest power. Distinctness of definition, by which is meant, the power of rendering all the minute lineaments clearly seen, is a quality of greater importance than mere magnifying power. Indeed, without this quality, mere magnifying power ceases to have any value, since the object would appear merely as a huge misty silhouette.

Sufficiency of illumination is another condition which it is difficult to combine with great magnifying power, but which is absolutely necessary for distinct vision.

If two instruments show the same object with equal distinctness of definition and with sufficiency of illumination, one having a higher magnifying power than the other, then it must be admitted that the one which bears, with such conditions, the higher power is the more efficient instrument.

The mere magnifying power depends on the focal length of the lenses, the illumination on the angle of aperture, and the distinctness of definition on the extent to which those conditions have been fulfilled which confer upon the combination of lenses composing the instrument, the qualities of aplanatism and achromatism.

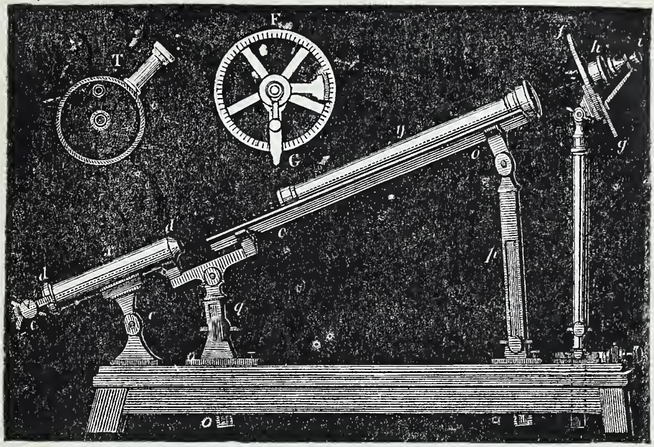


Fig. 35.—Biot's Polariscope.

THE MICROSCOPE.

CHAPTER V.

Micropolariscope : 69. Polarisation.—70. Condition of a polarised ray.—71. Polarisation by double refracting crystals.—72. Their effect upon rays of light.—73. The micropolariscope. The mounting of microscopes : 74. Conditions of efficient mounting.—75. Frauenhoffer's mounting.—76. Methods of varying the direction of the body. Chevalier's universal microscope : 77. Mounting of this instrument.—78. Method of rendering it vertical.—79. Method of adapting it to the view of chemical phenomena.—80. Method of condensing the light upon the object. Ross's improved microscope : 81. Useful labours of Mr. Ross. —82. Details of his improved microscope.

THE MICRO-POLARISCOPE.

69. When a ray of light has been reflected from the surface of a body under certain special conditions, or transmitted through certain transparent crystals, it undergoes a remarkable change in its properties, so that it will no longer be subject to the same effects of reflection and refraction as before. The effect thus produced upon it, has been called polarisation, and the ray or rays of light thus affected are said to be polarised.

The name POLES is given in physics in general to the sides or ends of any body which enjoy or have acquired any contrary properties. Thus, the opposite ends or sides of a magnet, have contrary properties, inasmuch as each attracts what the other repels. The opposite ends of an electric or galvanic arrangement are, for like reasons, denominated poles.

70. Following the common rule of analogy in nomenclature, a ray of light which has been submitted to reflection or transmission under the special conditions referred to, has been called polarised light; inasmuch as it is found that the sides of the ray which lie at right angles to each other, possess contrary physical properties, while those of a ray of common or unpolarised light possess the same physical properties.

To illustrate the relative physical condition of common light and polarised light, we may compare a ray of common light to a round rod or wire of uniform polish and uniformly white, while a ray of polarised light may be compared to a similar wire, two of whose opposite sides are rough and black, while the other opposite sides at right angles to these are polished and white. Thus, if A B C D, fig. 33, be a section of the former, the entire circumference A B C D is white and polished, and if A′ B′ C′ D′

Fig. 33.

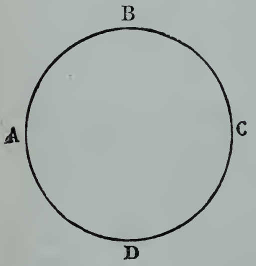
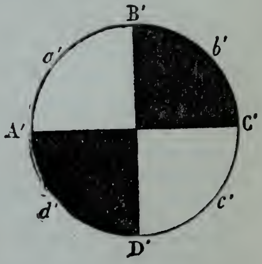


Fig. 34.



be a section of the latter, A′ B′ and C′ D′ will be white and polished, while B′ C′ and D′ A′ will be black and rough.

A group of physical properties, very numerous and complicated, characterise the polarised state of light, the discussion and exposition of which, constitute the subject of an extensive and important section of optics. It would be obviously impossible here to convey to the reader any general idea of these; nevertheless, as an illustration of them, one of the most frequent occurrence may be mentioned. If a ray of common light fall upon a smooth and polished surface, it is always reflected according to the well-known laws of reflection, no matter what side of it may be presented to the reflecting surface. If a polarised ray, however, fall at a certain inclination upon the same surface, it will be reflected or absorbed according to the side of it which is turned towards the reflecting surface. Thus, if the side A′ B′ or C′ D′ be presented towards the reflecting surface, the ray will be reflected as if it were common light, but if the side B′ C′ or A′ D′ be turned towards the reflecting surface, it will not be reflected at all, but will be, as it were, smothered or extinguished.

The sides A′ B′ and C′ D′, which are opposite to each other, have, therefore, a property contrary to that of the sides B′ C′ and A′ D′, so that they are respectively called the poles of the ray, just as the ends of a voltaic circuit having contrary electric properties are called the positive and negative poles of the voltaic battery, and the ends of a magnet are called its boreal and austral, or south and north poles.

The effects which polarised light produces when it falls upon, or is transmitted through, various substances, more especially such as are in the state of crystallisation, are of the highest physical importance, being in most cases the indication of molecular and other properties, by which optics has been placed in relation with, and has become the handmaid of, almost every other branch of physical science.

71. There are various expedients by which a ray of common light can be polarised. It will be polarised if it be reflected at a certain inclination, called from that circumstance the angle of polarisation, from certain surfaces. Each substance has its own angle of polarisation. That of glass, for example, is $35\frac{1}{4}$°. It is also polarised if it pass through certain transparent crystals. Some of these, while they polarise the ray, split it into two, both being polarised, but in planes at right angles to each other; that is, for example, the sides A′ B′ and C′ D′ being white in one, and black in the other.

The well-known mineral called Iceland spar is an example of this class of crystals.

Such crystals are called double-refracting crystals, because the two rays into which the ray of common light is split are refracted by the crystal in different directions, and according to different laws.

When a polarised ray is transmitted through such a crystal, according to certain conditions, it will either pass through it, as it would through any ordinary transparent medium, or will be extinguished by it, according to the side of the ray to which certain faces of the crystal are presented. Such crystal is related to the poles of the ray, therefore, in the same manner as the reflecting surface already described.

72. If either the reflecting surface or the crystal, placed under the necessary conditions, be carried round a polarised ray, A′ B′ C′ D′, so as to be successively presented to all sides of it, the ray will be completely reflected or transmitted when it is presented to *a′*, the middle of the side A′ B′. As it is moved from *a′* towards *b′*, the quantity of light reflected or transmitted will be less and less, until it comes to *b′*, when none will be reflected or transmitted, the ray being wholly extinguished. As it is moved from *b′* to *c′*, the light reflected or transmitted, small in quantity at first, will be continually greater and greater until it comes to *c′* the middle of C′ D′, when the ray will be wholly reflected or transmitted. As it is moved from *c′* towards *d′*, the quantity of light reflected or transmitted is less and less, until arriving at *d′* the ray is altogether extinguished. After passing from *d′* towards *a′*, the light reflected, at first small, is more and more in quantity until it comes in fine to *a′*, when the ray is, as at first, wholly reflected or transmitted.

73. An instrument adapted to show the effects of polarised light upon bodies on which it is incident or through which it is transmitted, is called a POLARISCOPE, fig. 35, p. 65, and a polarising microscope or MICRO-POLARISCOPE, is a microscope by which the observer is enabled to project polarised light upon the objects, and to observe its effects when transmitted or reflected by them.

Micro-polariscopes have been constructed in various forms, some depending on polarisation by reflection, and some on polarisation by transmission.

One of the most simple and most generally useful, consists of two prisms of Iceland-spar, one of which, P, is placed under the stage, so that the light by which the object is illuminated must previously pass through it, and the other P′ is placed in the body of the instrument between the object-glass and the eye-glass, so that before producing the image, the rays must pass through it.

The light proceeding from P, and projected upon the object, being polarised, and received, after passing through the object-glass, by P′, will be wholly or partially transmitted, or altogether extinguished, according to the sides or poles of the ray to which certain faces of the prism are presented. If, therefore, the instrument be so mounted that the prism P′ can be turned round its axis, its faces can be presented successively to all sides of the rays, so that the light will be in a certain position wholly transmitted, and the image will be seen strongly illuminated. When the prism is gradually turned round, the light transmitted will be less and less, until the prism has been turned through a quarter of a revolution, when the light will be wholly extinguished, and the image will disappear. Continuing to turn the prism, the image will gradually re-appear, at first faintly, and by degrees brighter, until the prism is moved through another quarter of a revolution, when the image will be again seen fully illuminated. Like changes will take place during the other two quarters of a revolution.

Similar effects will be produced if the prism P′ be fixed, and P be turned round its axis. In this case, by moving the polarising prism P round its axis, the polarised ray is made to revolve, because the position of its poles *a′ b′ c′ d′* has always a fixed relation to the faces of the prism P. Since, therefore, the polarised ray revolves, it presents successively all its sides to the prism P′, by which it is accordingly alternately transmitted, and absorbed wholly or partially in the same manner, exactly as if the ray were fixed, and the prism P′ carried round it.

By the appearance and disappearance of the image corresponding with the position of the prism P′, the position or direction of the planes of polarisation A′ C′ and B′ D′ of the polarised ray is known.

These effects will be produced if the objects through which the light is transmitted or by which it is reflected have themselves no polarising influence. But if they have, various other phenomena will ensue, depending on the character and degree of that influence; but whatever it be, the state of the light, which proceeding from the object-glass forms the image, will be ascertained by the prism P′, which is consequently called the *analysing prism*, the other P being denominated the polarising prism.

Various physical characters are thus discovered in the objects submitted to the microscope by determining the optical effects they produce on polarised light, and many striking and beautiful phenomena are developed.

THE MOUNTING OF MICROSCOPES.

74. The methods of mounting microscopes, so as to adapt them to the convenience and the ease of observers, are very various, depending on the purposes to which they are applied, their price, the exigencies of the purchaser, and the skill, taste, and address of the maker.

The qualities which it is desirable to confer upon the stand and mounting of the instrument are simplicity of construction, easy portability, smoothness and precision in the action of all the moving parts, and such combinations as may cause any tremor imparted to the stand to be distributed equally over every part of the mounting. These capital objects are attained very completely in all the mountings of the best makers, British and Foreign.

The most simple, and consequently the cheapest description of mounting, is that in which fewest parts are moveable. The only parts of a compound microscope which are *necessarily* moveable are those by which the instrument is focussed, and the object illuminated. The most simple mechanical expedient for effecting the former is a rack and pinion attached either to the body or the stage, and for the latter the suspension of the reflector upon an horizontal axis, so that it can be inclined at any desired angle to the axis of the body and the stage.

Whatever be the form or disposition of the stand, it is essential that the axis of the object-piece should pass through the centre of the stage, and that the reflector should be so set as to be capable of reflecting light in the direction of this axis. The body is generally a straight tube, the axis of the eye-piece and object-piece being in the same straight line. In the case of instruments mounted after the model of Professor Amici, however, the body consists of a tube having two parts with their axes at right angles, the axis of the object-piece being vertical, while that of the eye-piece is horizontal. In this case, a prism is fixed in the angle of the tube, at an angle of 45° with the axes by which the rays proceeding vertically from the object-piece are reflected horizontally to the eye-piece, on the principle already explained (30).

75. One of the most simple models for the mounting of a compound microscope was contrived by Frauenhoffer so early as 1816, long before achromatic lenses were produced. This model, owing to its great simplicity, convenience, and cheapness, is still extensively used for the lower priced instruments, especially by the continental makers.

The body of the instrument is attached to a vertical pillar, fig. 36, p. 49, and its axis is permanently vertical. It is focussed by a rack and pinion, worked by a milled head on the right of the observer. The stage is fixed in its position, and placed on the top of a short tube, in the lower part of which the reflector is suspended on an horizontal axis, so that it can be placed at any desired obliquity to the axis of the instrument, and thus can always throw a beam of light upwards to the object. One side of this mirror is concave, and the other plane.

For the illumination of opaque objects, a lens is attached by a jointed arm to the upper part of the pillar, on which the instrument is supported.

M. Lerebours, of Paris, makes excellent microscopes on this model, with a triple achromatic object-piece and other accessories, which he sells at the very moderate price of 90 francs (3*l.* 12*s.*). Several thousands of these have been sold.

76. The attitude of an observer stooping the head to view an object in a microscope, whose eye-piece is vertical, is found to be attended with much inconvenience, especially if the observation be long continued. This has constituted the ground of a very general objection to vertical microscopes. Nevertheless there are many cases in which it would be inconvenient to place the stage in an inclined or vertical position, as, for example, when observations are made on liquids. In all such cases the model of Amici's stand presents obvious advantages, the observer looking horizontally, while the axis of the object-piece is vertical, and consequently the stage horizontal.

Most of the better class of instruments, however, are so mounted that any direction whatever can be given to the axis of the body. Various mechanical expedients are used for accomplishing this, most of which are analogous to the methods of mounting telescopes. In some, the instrument with its appendages is supported upon two uprights of equal height by means of trunnions, which pass through its centre of gravity, so that it turns upon its supports like a transit instrument, the axis of the body being capable of assuming any inclination to the vertical. The observer, therefore, may at pleasure look obliquely or vertically downwards, or obliquely upwards, as may suit his purpose.

Similar motions are also produced by mounting the instrument upon a single pillar by means either of a cradle-joint, such as is generally used for telescope-stands, or a ball and socket. Stands of this form are attended with the advantages of offering greater facility for moving the instrument horizontally round its axis.

In the attainment of all these objects, as well as in the production of eye-pieces and object-pieces of capital excellence, the leading makers of London, Paris, Berlin, and Vienna, have honourably rivalled each other, and it may be most truly said, to their credit, that if some have excelled others in particular parts of the instrument, there is not one who has not in some way or other contributed by invention or contrivance to the perfection either of the optical or mechanical parts.

Much however is also due to the eminent philosophers and professors who have more especially devoted their attention to those parts of science in which the microscope is a necessary means of observation, and foremost among these is the patriarch of optical science, Sir David Brewster. It would be difficult to name the part of the instrument, or of its accessories or appendages, for the improvement of which we are not deeply indebted to this eminent man. Among the more recent philosophers who have contributed to the advancement of micrography, and by whose researches and suggestions the makers have been guided, may be mentioned Messrs. Goring, Lister, Coddington, Queckett, Mandl, Dujardin, Le Baillif, Seguier, De la Rue, and numerous others.

The eminent makers of the British and Continental capitals are well known. Good instruments of the low-priced sort are made by nearly all the opticians; but those who have more especially devoted their labours to the microscope, are Messrs. Ross, Smith and Beck, Powell and Lealand, Pritchard, Varley, and Pillisdier, in London; Messrs. Nachet, Charles Chevalier and George Oberhauser, of Paris; MM. Ploessel and Schieck, of Vienna; and M. Pistor, of Berlin.

Without the intention of assigning any relative precedence to these artists, we shall now present a brief description of some of the instruments, according as they are severally mounted by them.

CHEVALIER'S UNIVERSAL MICROSCOPE.

77. The mounting of this instrument has always appeared to me to offer as many conveniences and advantages to the observer as can be combined in such an apparatus.

A mahogany case A, fig. 37, p. 1, containing a drawer B, in which the instrument and its appendages are packed when out of use, serves as its support. A strong brass pillar, C C, is firmly screwed into the top of the case, and upon this pillar the entire instrument is supported.

The pillar C C sometimes is made in two lengths, which are screwed one upon the other, by which means the height of the instrument may be varied at pleasure, either one or both lengths being used.

An arm E *c* is attached by a joint at E to the summit of the pillar C C, so that it can be moved on the joint E with a hinge motion, and may thus be placed at any angle with the pillar C C. In the figure it is represented at right angles with C C.

To the middle D of the arm E *c*, a square brass bar D F G is attached at right angles to E *c*, so that when E *c* is at right angles to C C, the bar D F G is parallel to C C. In the face of the bar D F G, which is presented to C C, a rack is cut.

Two square pieces P and M are fitted to the bar D F G, and are moved at pleasure upwards and downwards upon it by means of pinions, having milled heads O and N.

To the square piece P is attached the stage Z, upon which the object is placed, and maintained in its position by two springs, one of which is shown in the figure. This stage is provided with several adjustments, which have been already explained (31 *et seq.*). It will be sufficient for the present to observe that it is capable of being moved upwards and downwards with the square piece P, to which it is attached by turning the milled head O, and that a slower motion, to give more exact adjustment, is imparted to it by a fine screw having a milled head at Q.

To the square piece M is attached the illuminator H, on one side, K, of which is a concave reflector, and on the other, I, a smaller plane reflector. This illuminator has two motions, a horizontal or lateral one upon a joint at M, by which it can be placed at pleasure either vertically under the centre of the stage Z, or at a limited distance on one side or other of the vertical through the centre of the stage. The circular illuminator is suspended at two points diametrically opposite in a semicircular piece, and may be placed at any desired inclination to the vertical, and with either reflector upwards by means of the milled head I.

From the lowest part of the pillar C C a piece projects, having a cavity corresponding with the size and form of the bar D F G, into which that bar enters when it is vertical as represented in the figure, and in which it is held by the pin at G.

The body of the microscope, as shown in the figure, is rectangular. The eye-tube T is moved backwards and forwards in the body R by a pinion U working in a rack. The eye-piece S is inserted in this tube, and the eye is protected from the light by a circular blackened screen, seen edgeways in the figure. The rectangular tube V X is inserted by a bayonet-joint in the remote end of the body R, in which it is capable of being turned, so that the object-tube X shall be horizontal, to enable the observer with greater facility to screw on or to change the object-glasses at Y.

The body is attached to the bar E *c* by a joint at *c*, upon which it can be turned, by which means other positions can be given to the instrument, as will presently be explained.

An assortment of object-glasses is supplied, which may be screwed at pleasure upon Y. They are adapted to each other in sets of three, so that one, two, or three may be attached to Y according to the power required.

In the angle *b* of the body, a rectangular prism is fixed, by which the rays proceeding upwards from Y are reflected horizontally along the axis of R to the eye-piece, on the principle explained in 30.

Several eye-pieces of different powers are supplied with the instrument.

The magnifying power may be varied within certain narrow limits by moving the eye-tube in or out by the pinion U, and at the same time adjusting the focus by the pinions O and Q, which move the stage Z. When it is desired to augment the power, the tube T is drawn out so as to lengthen the body, and the stage Z is brought nearer to the object-glass Y. The effect of this is to increase the dimensions of the optical image produced in the eye-piece by the object and field glasses, as explained in 6.

If a greater increase of magnifying power be desired, the eye-piece may be withdrawn, and a shorter one substituted for it.

But these expedients are only useful when the increase of power required is confined within comparatively narrow limits. All greater amplification must be produced by the object-glasses. These, as has been explained, are made in sets of three, having different powers. The lowest power will be obtained by screwing the first lens only of the lowest set upon Y; the next by screwing on the second; and the next by screwing on the third; by which the powers of all the three will be combined.

If it be desired to obtain a still higher power, these lenses being taken off, the first lens of the set next in order is screwed on, then the second, and in fine the third, by which another series of three increasing powers is obtained.

In this manner, by a suitable assortment of object-glasses and eye-pieces, any desired degree of amplification can be obtained.

The height of the case A and the length of the pillar C C are so arranged, that when the case is placed upon a table of the usual height, the eye of an observer of average height when seated will be on a level with the eye-piece S.

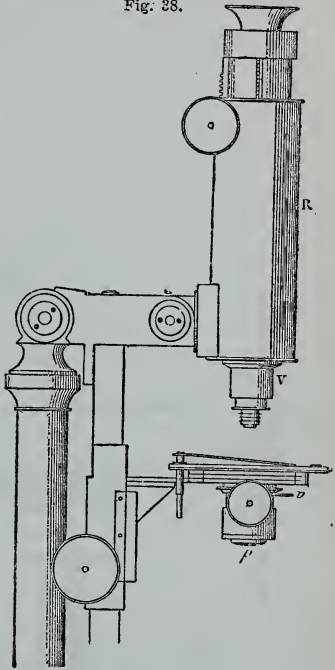
When the observer is about to submit an object to examination, having mounted the instrument, placed it firmly upon a table with an even surface so as to prevent any rocking or instability, and regulated the height of his seat so that his eye shall be at the level of the eye-piece, he selects an eye-piece and object-glasses having a suitable magnifying power, and in doing this it is most important to commence with a low power, to be gradually increased. For this purpose, one object-glass of a set is first screwed on, after which two, and in fine three, are used.

In this manner a survey is taken of the general outline and larger parts in the first instance, and the more minute parts afterwards.

78. The most generally convenient position for the instrument is that which is shown in fig. 37. If a vertical position be desired, it may however be easily obtained. For this purpose the rectangular piece V is drawn out of the bayonet-joint, and the object-tube is directly inserted in the body, so that its axis shall be horizontal and coincident with that of the body R and the eye-tube T. The body is then turned upon the joint *c* until it is raised into the vertical position. The relative position which the parts then assume is that which is shown in fig. 38.

79. When chemical phenomena are submitted to microscopic examination, and in general when liquids are observed which are liable to evaporation, it is found inconvenient to place the stage under the object-glass, inasmuch as the vapour proceeding from the liquid being more or less condensed upon it, destroys the clearness of the image.

Fig. 38.



Acid vapours sometimes rise from the substances under experiment, which often tarnish the object-glasses, and almost always corrode the metal of the instrument.

In such cases, therefore, it is necessary to provide means to place the liquid under observation in a glass capsule (a watch-glass, for example) above the object-glass, which must consequently be directed upwards, the stage supporting the capsule being over it.

To accomplish this, the rectangular piece V X is turned within the body upon its bayonet-joint through half a circumference, so that the object-tube X is presented vertically upwards, as shown in fig. 39. The arm *e f* carrying the stage *l*, the diaphragm *h* to limit the illumination, and the illuminating reflector or lens *g*, is then fixed upon the tube X; these pieces being severally moveable on the bar *e f* in the manner already described.

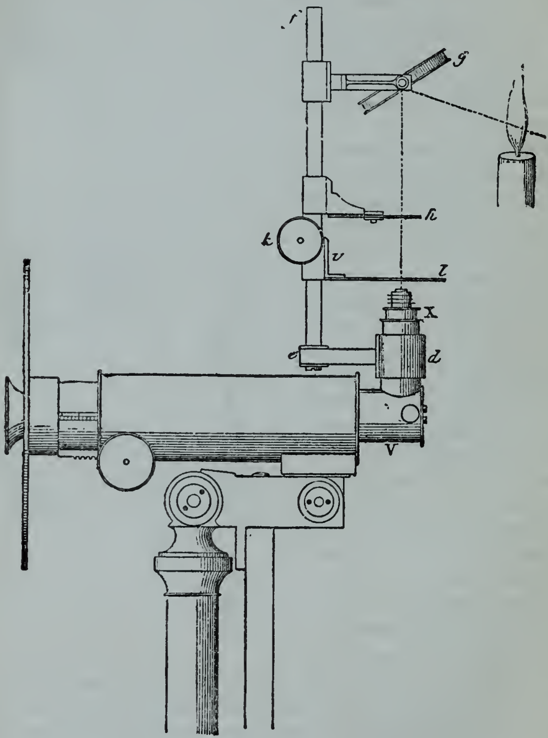
This arrangement is also useful when it is required to observe minute bodies which sink to the bottom of liquids, or animalcules which rarely come near the surface.

In certain cases, also, the circulation of the blood can only be observed with the instrument in this position.

80. It is sometimes desirable to direct the instrument horizontally towards the stage placed vertically. To accomplish this, it is only necessary, after arranging the instrument as shown in fig. 40, to turn the arm E *c* round through an angle of

90°, the pin G being withdrawn, so as to leave the bar D F G with the stage and its appendages free to turn on the joint E with the arm E *c*. The body R and the bar D F G will then be brought

Fig. 39.



into the horizontal position. The stage will then be vertical, and the object will be held in its position by the springs.

The illumination of the object may be produced either by the reflector or lens in the manner already described; or, if they are removed from the bar D F G, the stage may be presented directly to the light of the sun, the clouds, or a candle or lamp.

In some cases, however, when it is necessary to obtain a more intense illumination, an apparatus represented at *s s′* is employed, consisting of two convex lenses placed in the ends of a conical tube which slides upon the bar, by means of a square piece at the end of the arm *t*.

Besides the several motions above described, the body of the instrument has motion in an horizontal plane round the piece *a*,

Fig. 40.

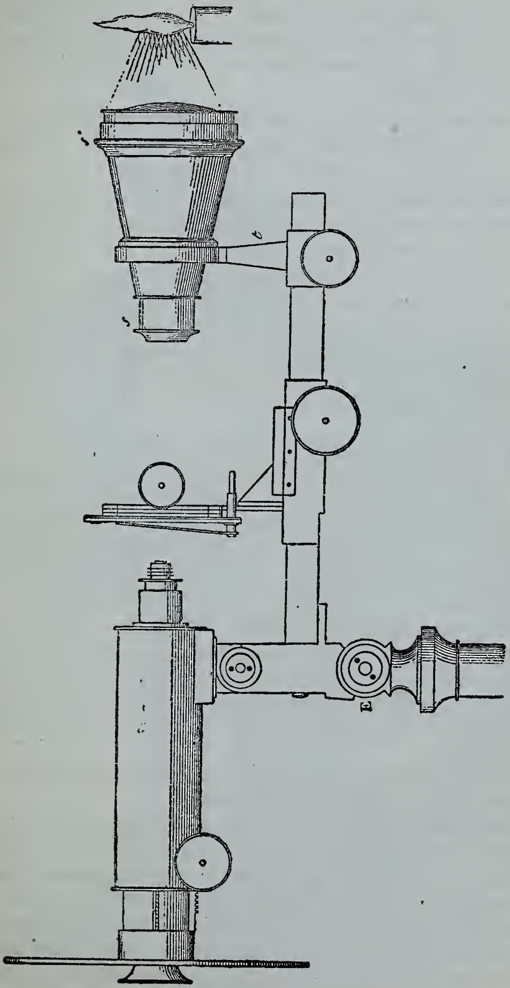


fig. 37, as a centre. This motion is very convenient when the instrument is used in the positions shown in figs. 37, 38, and 39, for the purpose of changing the angles. In general, and more especially when high powers are used, the object-glasses are so close to the stage, that they cannot be conveniently unscrewed and changed without either removing the object-tube from the stage, or the latter from the former. If, however, the body be turned horizontally upon the centre *a* through a few degrees, the object-tube will be removed from over the stage, and the lenses can easily be changed.

This method may also be practised in the positions shown in figs. 38 and 40, but it is more convenient to turn the rectangular piece Y X upon the bayonet-joint, as directed above.

Another advantage which attends this horizontal motion of the body round the centre *a*, is, that it enables the observer to direct the object-glass successively on different points of an object, the whole of which is not included in the field of view. This, however, can only be practised where low magnifiers are used.

To place this microscope in any desired inclined position, it is only necessary to place the body, as represented in fig. 38, and then taking out the pin G, fig. 37, to turn the bar D F G together with the body R into the desired inclination.

ROSS'S IMPROVED MICROSCOPE.

81. Mr. Ross holds a place in the foremost rank of philosophical artists, and deservedly enjoys an European celebrity.

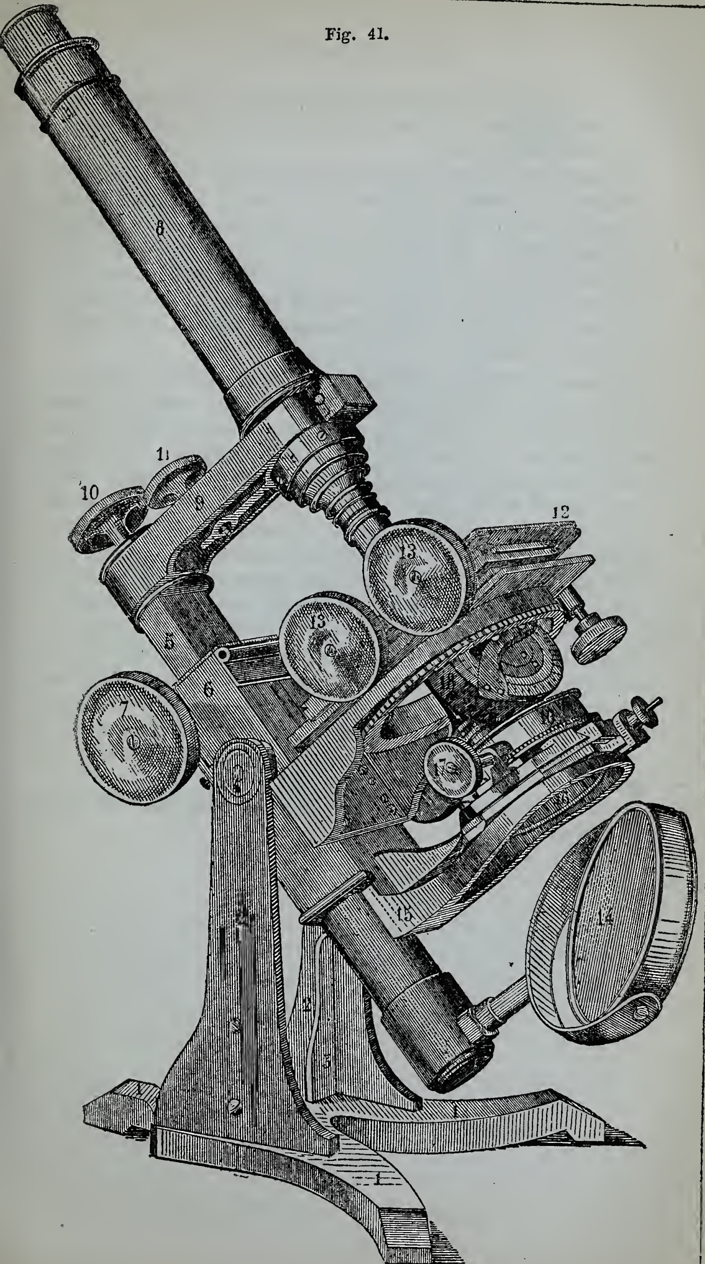
To his labours, perseverance, and genius, much of the perfection attained in the construction of object-lenses is due. The adjusting object-piece, already described, is one of his recent inventions (19).

In the progressive improvement which the microscope has undergone in his hands, the stand and the mounting, with the provisions for the arrangement of the accessories, have of course been more or less modified from time to time, and are at present varied according to the price of the instrument, and the purposes of the observer.

82. We shall here give a short description of the most recent form given by him to his best instruments.

Upon a tripod, 1, 1, fig. 41, are erected two upright pieces, 2, 2, strengthened by inside buttresses, 3. These uprights support an horizontal axis, 4, which passes nearly through the centre of gravity of the instrument, and upon which it turns, so that the axis of the body may be placed in any direction, vertical, horizontal, or oblique. The rectangular bar, 5, having a rack at the back, is moved in the box, 6, by the pinion, 7. The body, 8, is inserted in a ring at the end of the arm, 9, which latter is fixed upon a pin at the end of the rod, 5, upon which it turns, so as to remove

Fig. 41.



at pleasure the object-piece from over the stage, to change or clean the lenses. The arm, 9, can be fixed in its position by the pin, whose milled head is 10.

The instrument is focussed first by moving the body to and from the stage by means of the pinion, 7, and rack, 5, the adjustment being completed by a much slower motion imparted to the body by the milled head, 11, which is connected with a screw and lever, by one revolution of which the body is moved through the 300th part of an inch. An elastic play is allowed to the body, so as to guard against injury by the accidental contact of the object-piece with the slide.

The usual rectangular motions are imparted to the stage, 12, through the extent of an inch, by the milled heads, 13, which act on pinions, by which the racks are driven which carry the stage right and left, and backward and forward. The illuminating mirror, 14, is supported in the usual way, so as to be placed at any desired angle with the axis of the instrument. Below the stage is fixed an arm, 15, capable of being moved up and down by rack and pinion. This arm supports a tube, 16, intended to receive apparatus to modify the light transmitted by 14 to the object. Various apparatus for condensing and otherwise modifying the illumination are provided, which fit into this tube, 16. A motion of revolution round its axis is given to this tube by the milled head, 17. By these means, the effect of oblique light can be shown on all parts of the object. A condenser, 18, invented by Mr. Gillet, of a peculiar construction, provided with a series of diaphragms formed in a conical ring, is inserted beneath the stage.

Polarising apparatus, and other appendages, can also be attached to the secondary stage.

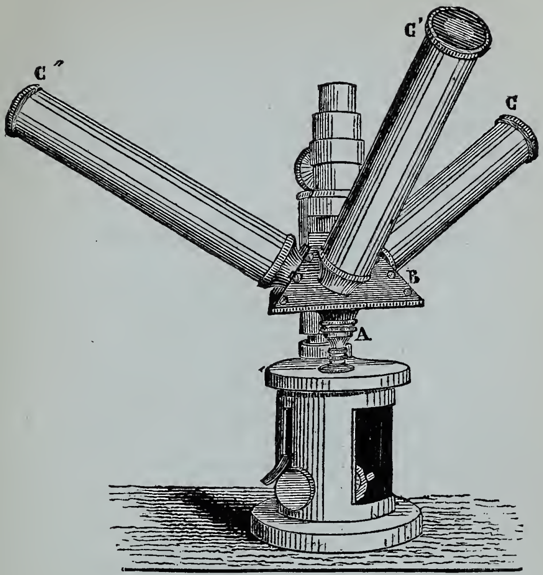


Fig. 45.—NACHET'S TRIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER VI.

83. His object-glasses. MESSRS. SMITH AND BECK'S MICROSCOPE : 84. Their largest and most efficient instrument.—85. Their smaller microscope. —86. Their object-glasses.—87. Varley's microscope. M. NACHET'S MICROSCOPE : 88. Their adaptation to medical and chemical purposes. —89. Multiple microscopes.—90. Double microscope.—91. Binocular microscope.—92. Triple and quadruple microscopes.

83. WITH his largest and best instruments, Mr. Ross supplies four eye-glasses and eight object-glasses, by which thirty-two varieties of power and illumination may be obtained. The object-glasses vary from two inches to a 12th of an inch in focal length, and from 12° to 170° in angular aperture. The following

is a tabulated statement of the powers resulting from these combinations, the four eye-glasses being designated in the order of their powers, by the letters A, B, C, and D. The prices of the object-glasses severally are given in the last column of the table, and the slightest reference to them will explain the general desire of microscopists to diminish expense, by varying their powers, by the expedient of separating the lenses which enter into the composition of the object-pieces.

Achromatic Object-glasses for Microscopes.

Object-glasses.	Angular Aperture.	Magnifying Powers with the various Eye-glasses.				Price.		
		A.	B.	C.	D.	£	s.	d.
2 inches . .	12 degrees.	20	30	40	60	3	0	0
1 ,, . .	15 ,, .	60	80	100	120	2	0	0
1 ,, . .	22 ,, .	,,	,,	,,	,,	3	10	0
½ ,, . .	65 ,, .	100	130	180	220	5	5	0
¼ ,, . .	85 ,, .	220	350	500	620	5	5	0
⅙ ,, . .	135 ,, .	320	510	700	910	10	0	0
⅛ ,, . .	150 ,, .	420	670	900	1200	12	0	0
$\frac{1}{12}$,, . .	170 ,, .	650	900	1250	2000	18	0	0

When angular apertures, so extreme as those indicated in the preceding table, are attempted, it is necessary that the object-lens presented to the pencil diverging from the object, shall be of the meniscus form, the concave side being turned towards the object, for the reasons explained in 19.

Besides the larger class of instruments above described, Mr. Ross constructs microscopes in a variety of other forms, which are placed within the reach of those who do not find it convenient to incur the expense of the larger instrument.

MESSRS. SMITH AND BECK'S MICROSCOPE.

84. The largest and most efficient class of instruments constructed by these artists, do not differ much in their mounting from those of Mr. Ross above described. Like the latter, they are supported by a horizontal axis, between two strong vertical pillars, screwed into a tripod base. The instrument with its appendages, turning on the horizontal axis, can thus be placed at any obliquity whatever with the vertical. The coarse adjustment of this microscope is made by a rack and pinion, by which

the entire body is moved to and from the stage. The object-piece is set in a tube, which moves within the principal tube of the body, the motion being imparted to it by a fine screw with a milled head, which constitutes the fine adjustment. Two different kinds of stage are supplied, one called the lever stage, consisting of three plates of brass, the lowest of which is fixed, and the other two provided with guides and slides, and a lever by which they may be moved, together or separately, in directions at right angles to each other; the other form of stage also has two motions at right angles to each other, one produced by rack and pinion, and the other by a screw whose axis is carried across the stage, and is turned by the left hand, while the rack and pinion is turned by the right hand.

85. Messrs. Smith and Beck also construct other forms of microscope, which, though perfectly efficient, are cheaper and more simple; one of these is represented in fig. 42, p. 17. It is mounted upon a vertical pillar, supported on a tripod T; the body of the microscope plays upon a cradle joint, to which the bent arm U U is attached; the body of the instrument is moved by a rack and pinion in a triangular groove formed in the upper part of this arm; the coarse adjustment is made by the milled heads which move the entire body to and from the stage. In the lower end of the body, a tube is inserted, from which an arm projects, in which a fine screw plays, which is connected with another arm attached to the body of the instrument: by turning the milled head, a slow motion is therefore imparted to the tube thus inserted in the lower extremity of the body. In the end of this tube the object-piece is set, so that the fine adjustment is made by this screw.

To the lower end of the bent arm U U, the stage and its appendages are attached; two motions at right angles to each other are imparted to the stage, by milled heads; the reflector is mounted in the usual way, and provisions are made under the stage, by which achromatic condensers, polarisers, and other apparatus can be applied; the disc of diaphragms is shown at L; it is mounted on a short piece of tube, in which polarising and other apparatus may be inserted.

86. Messrs. Smith and Beck supply with their best microscopes three eye-pieces and five object-pieces, the powers of which, as well as their angles of aperture, are indicated with their prices in the annexed table.

Achromatic Object-glasses for the Microscope.

Focal length.	Linear Magnifying Power nearly.*	With Eye-pieces. No.1.	No.2.	No.3.	Angle of aperture about	Price. £	s.	d.	Lieoer-kuhn additional. s.
$1\frac{1}{2}$ inch	Draw-tube closed	20	45	80	13 degs.	3	0	0	15
	Add for each inch of tube drawn out	4	6	8					
$\frac{2}{3}$ inch	Tube closed . .	60	105	180	27 degs.	3	3	0	11
	Add for each inch of tube . . .	7	12	20					
$\frac{4}{10}$ inch	Tube closed . .	120	210	350	55 degs.	5	5	0	10
	Add for each inch of tube . . .	12	20	35					
Ditto	Ditto . . .	do.	do.	do.	65 degs.	6	6	0	10
Ditto	Ditto . . .	do.	do.	do.	75 degs.	7	7	0	10
$\frac{1}{5}$ inch	Tube closed . .	240	430	720	85 degs.	6	6	0	
	Add for each inch of tube . . .	30	45	80					
Ditto	Ditto . . .	do.	do.	do.	100 degs.	7	7	0	
$\frac{1}{8}$ inch	Tube closed . .	450	760	1300	100 degs.	8	8	0	
	Add for each inch of tube . . .	40	60	115					
Ditto	Ditto . . .	do.	do.	do.	120 degs.	10	10	0	

* With the $\frac{2}{3}$ inch object-glass and the erecting-glasses, employing eye-pieces Nos. 1 and 2, the magnifying power will range from 5 to 150.

Among the accessories of the microscope due to Messrs. Smith and Beck, we must not omit to mention the microscope-table, contrived to facilitate the observations of several persons directed to the same object with the same microscope. Every one who has used this instrument is aware how fatiguing it is to several persons to succeed one another in observing with the same instrument. They are obliged constantly to shift their position, and consequently to make their observation standing. The microscope-table, if it do not entirely remove this inconvenience, greatly diminishes it. It is a circular table, firmly supported on a pillar and claw, capable of being turned with a smooth motion round its centre in its own plane. The observers sitting round it, the microscope is moved successively to the position occupied by each of them by merely turning the table. The best sort of these tables are made with a plate-glass top, and surrounded by drawers, in which the apparatus can be conveniently assorted.

MR. VARLEY'S MICROSCOPE.

87. This artist has constructed instruments with provisions similar to those already described; they are somewhat different in their form and details. He has, however, recently introduced a microscope, which claims the advantage of enabling the observer to examine living objects, such as animalcules, notwithstanding the inconvenience arising from their restless mobility, causing them continually to escape from the field of view. The stage motion with its appendages, contrived by Mr. Varley, enables the observer, without difficulty, to pursue the object.

He has also contrived a phial-microscope, by which aquatic plants and animals can be conveniently observed.

M. NACHET'S MICROSCOPES.

88. M. Nachet, of Paris, has acquired an European celebrity for the excellence of his instruments, and for the various inventions and improvements in their construction, by which he has extended their utility. He has constructed instruments in various forms, according to the uses to which they are to be applied and their price. For medical and chemical purposes, the body of the microscope slides in a vertical tube, the coarse adjustment being made by a rack and pinion, and the fine by a screw. The stage is firmly fixed under the object-piece, at the top of a hollow cylinder, within which the illuminating apparatus and other appendages are included.

89. One of the most recent novelties due to this eminent artist, is a form of microscope by which two or more observers may, at the same time, view the same object, thus conferring upon the common microscope a part of the advantages which attend the solar microscope. This is accomplished by connecting two or more tubes, each containing its own eye-piece, with a single tube containing an object-piece; it has been already shown that the axis of the tube containing the eye-piece may be placed at any desired inclination, with that which contains the object-piece, by placing in the angle formed by the two tubes, a reflector, or reflecting prism, in such a position, that the pencils of rays proceeding from the object-piece shall be reflected to the eye-piece, without otherwise deranging them. It is evident, therefore, that if the rays proceeding from the object-piece could be at the same time received by two or more reflectors, so placed as to reflect them in two or more directions, they might be transmitted along two or more tubes in these directions to two or more eye-pieces, through which the same object might thus be viewed at

the same time, and through the same object-piece by two or more different observers.

Such is the principle upon which the multocular microscope of M. Nachet is based.

90. A double instrument of this description is shown in fig. 43, where A is the object-piece directed vertically downwards on the stage; above it is a case, containing a triangular prism which is so formed that the light reflected from its left side shall pass along the axis of the right-hand tube, and that reflected from its right side along the axis of the left-hand tube. Observers looking into eye-glasses set in these tubes, would therefore both see the same object in precisely the same manner.

It may perhaps be objected, that the focus which would suit the eye of one observer, would not suit the other; the difference, however, between the focal adjustments of different eyes is always so inconsiderable, that it can be equalised by a small motion given to the tubes carrying the eye-pieces.

Microscopes, as they are usually mounted, reverse the objects, the top appearing at the bottom, the right at the left, and *vice versâ*. This being found inconvenient in instruments used for dissection, where the motion of the hand and the scalpel of the operator would be reversed, expedients are provided by which the

Fig. 43.

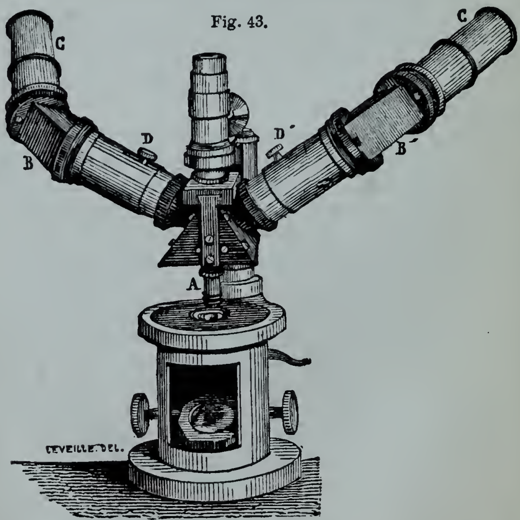
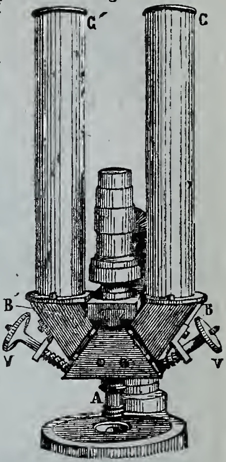


image is redressed, and the object viewed in its natural position. This is accomplished in the microscope represented in fig. 43, by two prisms fixed at B B′ in the tubes, which are placed at right angles to the lower prism A; by this second reflection, the reversed image of the first reflection, being again reversed, is made to correspond with the natural position of the object.

Fig. 44.



91. An interesting variety of this form of instrument, which may be called a BINOCULAR MICROSCOPE, is shown in fig. 44. In this case the two tubes, B C and B′ C′, containing the two eye-pieces, are placed parallel to each other, the distance between them being regulated by the screws V V; if this distance be so adjusted as to correspond with the distance between the eyes of the same individual, the microscope may be used with both eyes, in the same manner as a double opera-glass. This has the advantage of giving a stronger appearance of relief to the objects viewed, which is especially desirable for a certain class of objects, such as crystals.

92. A triple microscope, upon the principle above described, is shown in fig. 45, p. 81, where A is the object-piece, B the multiple prism, and C, C′ and C″ the three eye-tubes.

A similar instrument, with four eye-tubes, including figures to illustrate the mode of observing with it, is shown in fig. 46, p. 33.

One of the advantages of this class of instruments is, that a professor and one or more of his pupils may view the process of a microscopic dissection which with a common microscope would be impossible, and to which the solar microscope would be inapplicable. Microscopic dissections, in general, can only be exhibited to those who do not execute them, by their ultimate results. Any phenomena which are developed in their progress, can only be made known to others by description; and it is not necessary to say, how imperfect such a mode of communication must be, compared with direct observation.

Fig. 5.—MAGNIFIED VIEW OF THE LURCO OR GLUTTON.

MICROSCOPIC OBJECTS.

1. Microscopic objects.—2. The dragon-fly and its larvæ.—3. The satyr. —4. The linceus sphericus.—5. The lurco, or glutton.—6. The water-fly.

1. HAVING in the preceding Tract explained the structure, application, and use of the microscope in the various forms which have been given to that instrument, we shall here briefly notice a few remarkable microscopic objects, selected chiefly from the Microscopic Cabinet of Mr. Pritchard, illustrated with magnified drawings by the late Dr. Goring.

2. The family Libellulidæ includes an extensive and beautiful group of large insects not sensibly differing in their external form from the ant-lion, already noticed.*

* Instinct and Intelligence, p. 119.

These are popularly known by the names of horse-stingers and dragon-flies. The former name is founded on a vulgar error, since the animal has no sting. The illusion implied by the latter is, however, more correct, since the insects, both in their appearance and voracious habits, are certainly more entitled to the name of dragons than that of demoiselles, or lady-flies, by which they are commonly known in France.

Fig. 1.

The beautiful appearance of these insects on the wing, their varied colours, the gauze-like structure of their wings, and the rapidity of their flight, must have attracted general attention. In hot summer days, they may be seen darting backwards and forwards in the air over standing pools, which supply them abundantly with the insects on which they feed. Their colours are subject to much diversity, the males having an abdomen of leadish blue, while that of the females is a yellowish brown. In some species, the males have a rich bright blue colour, with black wings, while the females are distinguished by a fine green, with colourless wings.

After impregnation, the female hovers over the surface of the water until she selects a place for the deposition of her eggs, which she deposits one by one in the water, beating the surface with her tail while she lays them, until at length they are collected into a mass resembling a bunch of grapes.

The larvæ on issuing from the egg are so minute as to be scarcely perceptible to the naked eye. In some days, however, they attain the length of the tenth of an inch, and cast their skin f•r the first time. To the naked eye they appear in this state like black spots, to which a tail is attached. When well fed they grow rapidly; and when they have attained the length of about a quarter of an inch, they begin to display their characteristic courage and ferocity, attacking, with open mouth, creatures ten times their own bulk; and, when pressed by hunger, devouring each other.

The magnified drawing of this larva, from which fig. 2 was

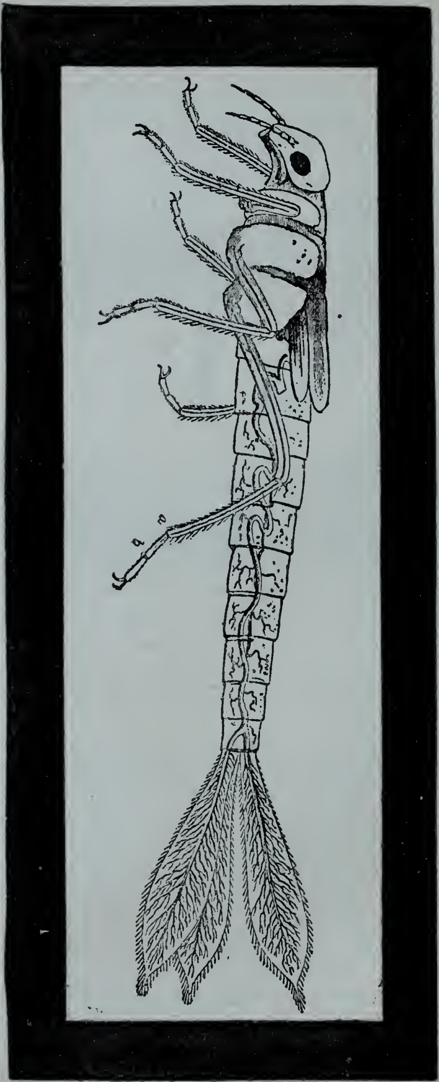


Fig. 2.—MAGNIFIED VIEW OF THE LARVA OF A SPECIES OF DRAGON-FLY DRAWN BY DR. GORING.

taken, was made by Dr. Goring, and published with a description by Mr. Pritchard in the Microscopic Cabinet. The real length of the creature, measured from the extremity of the antennæ tc that of the tail, was eight-tenths of an inch. It is represented in the figure, as seen in profile, the breadth of the head and other parts being necessarily foreshortened.

A system of tracheæ, with numerous ramifications, passes along each side of the body from the head to the tail, one of which is seen in the figure. These respiratory apparatus ramify in a beautiful manner in the triple branches of the tail, each of which receives a branch from each trachea.

During its growth the larva casts its skin several times, and the skin which it thus throws off, being translucent, is an interesting and beautiful microscopic object.

The eyes as well in the larva as in the perfect insect are very salient, and from their magnitude and structure form interesting microscopic objects. Like those of some other insects described in a former Tract,* they consist of a multitude of distinct organs of vision, each of which is an hexagonal lens. It was observed by Latreille, that their number increased in proportion to the voracity of the insect. Leuwenhoeck counted 12000 in a single insect. Each hexagon is a convergent lens, which may be converted into a microscope. Each of these lenses is found to produce an inverted image of an object to which it is presented.

3. The object shown in fig. 3, engraved from a drawing by Dr. Goring, and described in the Microscopic Cabinet by Mr. Pritchard, belongs to the class of animalcules denominated by Müller monoculi, from the circumstance of their having a single organ of vision, *a*, placed in the centre of the front of the head. This specimen is called the satyr, and is the amymone satyr of Müller. The figure represents a magnified view of the full-grown insect, seen at the inferior surface of its body as it presents itself to the observer, attached to the inner surface of a vase of water in which it moves. The real length of the animalcule here represented was the 120th of an inch. When they are

Fig. 3.

* "Microscopic Drawing and Engraving," p. 50.

young they are much smaller, and being then perfectly translucent, are highly interesting microscopic objects. They are found in abundance in the months of March and April, at the surface of shallow pools of clear water which contain aquatic plants.

The back of this animalcule is protected by a tender and transparent shell, the belly being naked and membranous. Seen in profile it resembles a tortoise, but, as shown in the figure, it has the form of a horse-shoe. It has four feet, and two antennæ attached to the inferior part of the body, and radiating from a common centre. Placed in the middle of the head, between the two antennæ, *b*, are the mouth and the single eye, *a*, the latter being black, and set in a square orbit of a deep crimson colour. Each of the antennæ has four articulations, and is furnished with bristles at its extremity. The feet, *c c*, are divided at the second joint, and terminate in strong pincers. The peristaltic motion of the alimentary canal can be distinctly perceived with the microscope, by observing the dark lines which run along the body of the animalcule. On each side of this canal are placed the ovaries, *d*, which, when they are fully developed, are distinguished by their dark colour. The satyr swims by sudden impulses, moving the feet rapidly, and sometimes appears to slide along the internal surface of the vase.

4. The animalcule represented in fig. 4, and reproduced from a drawing by Dr. Goring, is the linceus sphericus of Müller, miscalled monoculus minutus by Linnæus, since it has two eyes sufficiently apparent. The figure is reproduced from the Microscopic Cabinet of Mr. Pritchard, where the animalcule is described.

Fig. 4.

The shell or cuirass, which is quite translucent, consists of a single piece, without any perceptible articulation. It possesses, however, sufficient elasticity to allow the animal to open it at will, after the manner of a common mussel. The two edges of the opening are seen in the figure at *a*, the figure being understood to present a profile of the object. The two eyes, *a*, have different magnitudes, and their black colour presents a striking contrast with the surrounding parts. They are encased in the shell by which they are protected. The beak, *b*, is pointed, and participates in the general convexity of the shell. Under it is placed a second beak-like projection, somewhat shorter, and having three coarse hairs at its extremity, which probably serve the purpose of palpi or feelers. Below this are placed the two antennæ, *c*, each of which is terminated by similar but longer hairs. The false feet or branchiæ, which are four in number and ranged along the edge of the shell, are covered with hairs, and terminate like the antennæ; by their action a rotatory motion is imparted to the animalcule, which is accelerated by the action of the projecting part, *d*, against the water. This part is ciliated on its posterior edge, and armed at its extremity with strong claws. The ovaries, which appear at *e*, have a greenish-blue colour, and the form of a mulberry. The convolutions of the alimentary canal with the food contained in it are visible with the microscope from one extremity to the other.

But the most remarkable organ is a small oval body placed behind the head and shown in the upper part of the figure. This body has a rapid motion of pulsation.

5. These creatures feed upon animalcules, and in their turn become themselves the prey of aquatic larvæ and coleoptera, such as the water-beetles. They are the especial food of the lurco, or glutton (the larva of the naid), a magnified view of which is shown in fig. 5, with several lincei, *c*, visible within it. The young ones are seen playing around the mother, and on the approach of an enemy they rush for protection under her cuirass, which she immediately closes upon them.

6. The crustaceous animalcule represented in B, fig. 1, in its natural size, and in A, fig. 2, magnified, is the four-horned cyclops, or little water-fly; the cyclops quadricornis of Müller, the monoculus quadricornis of Linnæus, and the pediculus aquaticus, or water-louse, of Baker. The figure was drawn by Dr. Goring, and described by Mr. Pritchard in the Microscopic Cabinet.

This little animal is found at all seasons in water, but more especially in the months of July and August, when it may be easily taken by a net at the depth of about an inch below the surface.

The body is covered with scales, which have a vertical and lateral motion. Their edges do not meet under the insect, but leave a space for the insertion of the organs of respiration, *a*. The beak is short and pointed, and is a mere prolongation of the first segment of the body. A little above it is inserted in the cuirass a single eye of a crimson colour, so dark as to approach nearly to black. On each side of the eye are inserted the antennæ, of which there are two pair, the superior being longer than the inferior. They are composed of numerous articulations, from each of which issue two or several hairs. In some species the sexes are distinguished by the form of these appendages, being straight and thicker, with an enlargement towards the middle of their length, in the male, as shown in fig. 4.

These insects move by sudden jumps or plunges, but sometimes creep along the twigs of plants, in which movements they are

A

aided by their feet or branchiæ. These members are in almost incessant motion, a circumstance which renders the observation of their precise form in the living animal difficult. One of them is represented as seen under a higher magnifying power in A, fig. 3; they are generally transparent, but sometimes have a greenish-blue colour.

The ovaries consist of two sacs, which have the appearance of bunches of grapes attached to either side of the posterior extremity of the body, as shown in A, fig. 2. The eggs are globular, and are enclosed in a transparent membrane. The centre of each egg has an opaque colour, some being green and others red. Their number increases with the age of the female, and when they have attained a sufficient maturity the embryo of the future animal may be seen within them with a magnifier. Mr. Pritchard has distinctly seen these with a single lens with a focal length of about the 25th of an inch. At the extremity of the alimentary canal the tail

B

divides into two portions, whose extremities are fringed with bristles, which present the appearance of splendid plumes.

The alimentary canal and its peristaltic movements are distinctly visible in specimens which are only slightly coloured. Above this canal two others can be observed, through which the eggs are projected to the ovaries at each side of the tail

The colours of the coat of these insects vary in different individuals, as well as the colours of their ovaries, some being of a greenish-blue, and others red with green ovaries.

Another variety of this, called by Müller the cyclops minutus, or little cyclops, and popularly the jumper, is shown in B, fig. 5, as drawn by Dr. Goring, the animalcule being in a bent position, one of its characteristic attitudes. The real length of this specimen was about the 250th of an inch.

The structure of the coat, or cuirass, is similar to that of the animalcule represented in A, fig. 2, but it has a greater number of segments and a more graceful outline. The single eye is encrusted in the shell. The antennæ have not as many articulations as those of fig. 2, and the inferior pair of palpi is more plumed at the extremities. The most remarkable distinction between the two species is, that the latter is much smaller and supplied with only a single gill or respiratory organ under its beak. It has ten feet, and the female carries only a single bunch of eggs under the abdomen. In some individuals the respiratory organ observed by Mr. Pritchard has the form represented in B, fig. 6.

Fig. 1.—The Termes Embia.

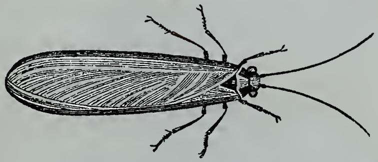


Fig. 2.—The Termes Fatalis, or Bellicosus, with wings folded.

Fig. 3.—Termes Fatalis, or Bellicosus, with wings expanded.

Fig. 4.—The King.

THE WHITE ANTS.

THEIR MANNERS AND HABITS.

CHAPTER I.

1. Their classification.—2. Their mischievous habits.—3. The constitution of their societies. — 4. Chiefly confined to the tropics.—5. Figures of the king and queen.—6. Of the workers and soldiers.—7. Treatment of the king and queen.—8. Habits of the workers.—9. Of the soldiers.—10. The nymphs.—11. Physiological characters.—12. First establishment of a colony.—13. Their use as food and medicine.—14. The election of the king and queen.—15. Their subsequent treatment.—16. The impregnation of the queen.—17. Figure of the pregnant queen.—18. Her vast fertility.—19. Care bestowed upon the eggs by the workers.—20. The royal body-guard.—21. The habitation of the colony.—22. Process of its construction.—23. Its chambers, corridors, and approaches.—24.

Vertical section, showing its internal arrangement.—25. View of these habitations.—26. Contrivances in their construction.—27. Use made of them by the wild cattle.—28. Used to obtain views to seaward. —29. Use of domic summit for the preservation of the colony.—30. Position, form, and arrangement of the royal chamber—its gradual enlargement for the accommodation of the sovereigns.—31. Its doors.—32. The surrounding antechambers and corridors.—33. The nurseries.—34. Their walls and partitions.—35. Their position varied according to the exigencies of the colony.—36. The continual repair and alterations of the habitation.—37. Peculiar mould which coats the walls.—38. The store-rooms for provisions—the inclined paths which approach them—the curious gothic arches which surmount the apartments.—39. The subterranean passages, galleries, and tunnels.—40. The covered ways by which the habitation is approached.—41. The gradients or slopes which regulate these covered ways.—42. The bridges by which they pass from one part of the habitation to another.—43. Reflections on these wonderful works.—44. The tenderness of their bodies render covered ways necessary.—45. When forced to travel above ground they make a covered way—if it be accidentally destroyed they will reconstruct it.

1. Of all the classes of insects which live in organised societies, the most remarkable after the bee are the family Termitinæ, popularly known under the name of white ants, though they have little in common with the ant, except their social character and habits.

Much discordance has prevailed among naturalists respecting their history and classification. They were assigned by Linnæus to the order Aptera, or wingless insects. More exact observation has, however, proved this to be erroneous; since, in the perfect state, they possess membranous wings like those of the dragon-fly, which being four in number, they have been more correctly assigned to the order Neuroptera. Kirby regards them as forming, together with the ants, a link between the orders Neuroptera and Hymenoptera, being allied to the latter by their social instincts.

2. Scarcely less remarkable than the bee in their social organisation, they differ from that insect inasmuch as while the labours of the latter are attended with no evil to mankind, but are, on the contrary, productive of an eminently useful and agreeable article of food, the Termites, so far as naturalists have yet discovered, are productive of nothing but extensive and unmitigated mischief.

3. These insects live in societies, each of which consists of countless numbers of individuals, the large majority of which are apterous, or wingless. Two individuals only in each society, a male and a female, or according to some, a king and a queen, are winged, and these alone in the entire society are specimens of the perfect insect. The general form of their bodies is shown in

fig. 1 and fig. 2; the former representing the species called the *Termes embia*, with its wings expanded, and the latter the *Termes fatalis* or *bellicosus*, with its wings folded.

4. With the exception of two or three small species, such as the *Termes lucifugus*, described by Latreille and Rossi; the *Termes flavicollis*, described by Fabricius; and the *Termes flavipes*, described by Kollar, these insects are confined chiefly to the tropics.

5. Each society consists of five orders of individuals—

I. The queen or female.
II. The king or male.
III. The workers.
IV. The nymphs.
V. The neuters or soldiers.

The *Termes bellicosus* or *fatalis*, which is represented in fig. 2, with wings folded, is shown in fig. 3 with wings expanded.

The king or male, which never changes its form after losing its wings, is represented in fig. 4.

6. The worker is represented in its natural size in fig. 5, and the soldier in fig. 6.

A magnified view of the worker is given in fig. 7, and a similar magnified view of the forceps of the soldier in fig. 8.

7. The king and queen are privileged individuals, surrounded with all the respect and consideration, and receiving all the attendance and honours, due to sovereigns. Exempted from all participation in the common industry of the society, they are wholly devoted to increase and multiplication, the queen being endowed with the most unbounded fertility. Though upon first passing from the pupa state they have four wings, they lose these appendages almost immediately, and during the period of their sovereignty they are wingless. They are distinguished from the inferior members of the society by the possession of organs of vision, in the form of large and prominent eyes, their subjects being all of them blind.

8. The workers are by far the most numerous members of the society, being about a hundred times greater in number than the soldiers. Their bodies also, fig. 5, are less than those of the soldiers, the latter being less than those of the sovereigns. The entire industrial business of the society is performed by the workers. They erect the common habitation, and keep it in repair. They forage and collect provisions for the society. They attend upon the sovereigns, and carry away the eggs of the queen, as fast as she deposits them, to chambers which they previously prepare for them. They maintain these chambers in order, and when the eggs are hatched, they perform the part of nurses to the young,

feeding and tending them until they have attained sufficient growth to provide for themselves.

9. The soldiers, of whom, as already observed, there is not more than one to every hundred workers, are distinguished by their long and large heads, armed with long pointed mandibles. Their duty, as their title implies, is confined to the defence of the society and of their common habitation, when attacked by enemies.

10. The nymphs differ so little from the workers, that they would be confounded with them, but that they have the rudiments of wings, or, more strictly speaking, wings already formed, folded up in wing cases. These escaped the notice of the earliest observers, having been distinguished by Latreille.

11. Naturalists are not agreed as to the physiological character of these three classes of the society. Some consider the workers as the larvæ which, at a certain advanced period of their growth, are metamorphosed into the nymphs, which themselves finally pass into the state of the perfect winged insect.

According to Kirby, the soldiers correspond to the neuters in other societies of insects. As he observes, however, they differ from the neuters of the societies of Hymenoptera, which are a sort of sterile females. He conjectures that the soldiers may be the larvæ which are finally transformed into the perfect male insect. Great differences of opinion, however, prevail on this subject among entomologists.

For our present purpose, these doubtful questions, whatever interest they may have for naturalists, are altogether unimportant. What we desire at present to direct attention to, is the curious manners and habits of these insects, which have been ascertained by many eminent naturalists, and have been described with great minuteness by Smeathman in the seventy-first volume of the Philosophical Transactions, from whose memoir we shall here borrow largely.

According to Smeathman, the following is the manner in which the establishment of each colony takes place.

12. The pupæ or nymphs, which compose, as has been stated, part of a society, are transformed into the perfect insect, their wings being fully developed and liberated from the wing cases soon after the first tornado, which takes place at the close of the dry season, and harbingers the periodical rains. The insects, thus perfected, issue forth from their habitation in the evening, in numbers literally countless, swarming after the manner of bees. Borne upon their ample wings, and transported by the wind, they fill the air, entering houses, extinguishing lights, and being sometimes driven on board ships which happen to be near the shore. The next morning they are seen covering the surface of the earth

and waters, deprived of the wings which enabled them, for a moment, to escape their numerous enemies. They are now seen as large maggots, and, from being the most active, industrious, and sagacious of creatures, are become utterly helpless and cowardly, and fall a prey to innumerable enemies, to the smallest of which they do not attempt to offer the least resistance. Various insects, and especially ants, lie in wait for them; beasts, birds, and reptiles, and even man himself, all feed upon them, so that not one pair in many millions make their escape in safety, and fulfil the first law of nature by becoming the parents of a new community. At this time they may be seen running upon the ground, the male pursuing the female, and sometimes two pursuing one, and contending with the greatest eagerness for the prize, their passion rendering them regardless of the many dangers with which they are surrounded.

13. Mr. König, in an essay upon these insects, read before the society of naturalists at Berlin, says that, in some parts of the East Indies, the queens are given alive to old men for strengthening the back, and that the natives have a method of catching the winged insects, which he calls females, before the time of emigration. They make two holes in the nest; the one to windward and the other to leeward. At the leeward opening, they place the mouth of a pot, previously rubbed with an aromatic herb, called Bergera, which is more valued there than the laurel in Europe. On the windward side they light a fire of stinking materials, the smoke of which not only drives these insects into the pots, but frequently the hooded snakes also, on which account they are obliged to be cautious in removing them. By this method they catch great quantities, of which they make with flour a variety of pastry, which they can afford to sell very cheap to the poorer ranks of people. Mr. König adds, that in seasons when this kind of food is very plentiful, the too great use of it brings on an epidemic cholic and dysentery, which kills in two or three hours.

Mr. Smeathman says, that he did not find the Africans so ingenious in procuring or dressing them. They are content with a very small part of those which, at the time of swarming, or rather of emigration, fall into the neighbouring waters, which they skim off with calabashes, bringing large kettles full of them to their habitations, and parch them in iron pots over a gentle fire, stirring them about as is usually done in roasting coffee. In that state, without sauce or any other addition, they serve them as delicious food, and put them by handfuls into their mouths, as we do comfits. Smeathman ate them dressed in this way several times, and thought them delicate, nourishing, and wholesome. They are something sweeter, but not so fat or cloying, as the caterpillar or maggot of the palm-tree snout beetle, which is served up at all the luxurious tables of West Indian epicures, particularly of the French, as the greatest dainty of the Western World.

14. Troops of workers, apparently deprived of their king and queen, which are constantly prowling about, occasionally encounter one of these pairs, to which they offer their homage, and seem to elect them as the sovereigns of their community, or the parents of the colony which they are about to establish. All the individuals of such a swarm, who are not so fortunate as to become the objects of such an election, eventually perish under the attacks of the enemies above mentioned, and probably never survive the day which follows the evening of their swarming.

15. So soon as this election has been made, the workers begin to enclose their new rulers in a small chamber of clay, suited to their size, the entrances to which are only large enough to admit themselves and the soldiers, but much too small for the royal pair to pass through, so that their state of royalty is a state of confinement, and so continues during the remainder of their lives.

16. The impregnation of the female is supposed to take place after this confinement, and she soon begins to furnish the infant colony with new inhabitants. The care of feeding her and her male companion devolves upon the workers, who supply them both with every thing that they want. As she increases in dimensions, they keep enlarging the cell in which she is detained. When the business of oviposition commences, they take the eggs from the female, and deposit them in the nurseries. Her abdomen now begins gradually to extend, till, in process of time, it is enlarged to 1500 or 2000 times the size of the rest of her body, and her bulk equals that of 20000 or 30000 workers.

17. A drawing of the pregnant queen in her natural size is given in fig. 9.

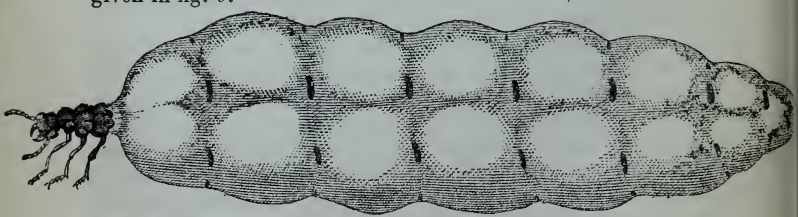


Fig. 9.—The Pregnant Queen.

18. The abdomen, often more than three inches in length, is now a vast matrix of eggs, which make long circumvolutions through numberless slender serpentine vessels: it is also remark-

able for its peristaltic motion (in this resembling the female ant), which, like the undulations of water, produces a perpetual and successive rise and fall over its whole surface, and occasions a constant extrusion of the eggs, amounting sometimes in old females to sixty in a minute, or eighty thousand and upwards in twenty-four hours. As these females live two years in their perfect state, how astonishing must be the number produced in that time!

19. This incessant extrusion of eggs must call for the attention of a large number of the workers in the royal chamber (and indeed it is always full of them), to take them as they come forth and carry them to the nurseries; in which, when hatched, they are provided with food, and receive every necessary attention until they are able to shift for themselves. One remarkable circumstance attends these nurseries. They are always covered with a kind of mould, amongst which arise numerous globules about the size of a small pin's head. This probably is a species of Mucor; and by Mr. König, who found them also in nests of an East India species of Termes, is conjectured to be the food of the larvæ.

20. The royal cell has in it a kind of body-guard to the royal pair that inhabit it; and the surrounding apartments always contain many, both labourers and soldiers in waiting, that they may successively attend upon and defend the common father and mother on whose safety depend the happiness and even existence of the whole community, and whom these faithful subjects never abandon, even in their last distress.

21. The habitations of the Termites, which are generally of considerable magnitude, vary in form, arrangement, and position, according to the species. Those of the *Termes bellicosus*, described above, have generally a sugar-loaf or hay-cock form, and are from ten to twelve feet high. In the parts of Africa where the insect prevails, these structures are so numerous that it is scarcely possible to find a spot from which they are not visible in all directions within fifty or sixty yards. In the neighbourhood of Senegal, according to Adanson, their number and magnitude is so great that they cannot be distinguished from the native villages.

22. When first erected, the external surfaces of these conical-shaped habitations consist of naked clay, but in these fertile climates the seeds of herbage transported by the wind are speedily deposited upon them, which germinating soon clothe them with the same vegetation as that which covers the surrounding soil, and when in the dry and warm season this vegetable covering is scorched, they assume the appearance of large hay-cocks.

23. These vast mounds are formed of earth which has been excavated by the workers from extensive tunnels which have

been carried beneath the ground surrounding their base, and which supply covered ways by which the workers are enabled to go forth in quest of provisions. The interior of the mounds themselves are of most curious and complicated structure, consisting of a variety of chambers and corridors, formed with the most consummate art, and adapted in shape and size to the respective purposes to which they are assigned in the general economy of the colony.

24. In the superior part of the mound, a dome is constructed, surmounting the habitations of the animals so as effectively to shelter them from the vicissitudes of weather. This may be seen in the vertical section of one of these mounds, shown in fig. 10. The exterior covering of this dome is much stronger than the internal structure beneath it, which constitutes the habitation of the colony, and which is divided with surprising regularity and contrivance into a vast number of chambers, one of which is appropriated to the sovereigns, and the others distributed among the soldiers, the workers, as nurseries, and as store-rooms.

The process by which these conical structures are raised is thus described.

25. The habitation makes its first appearance as one or two small sugar-loaf-shaped mounds about a foot in height. While these are gradually increasing in height and magnitude, others begin to appear near them, which likewise increase in number; and by the enlargement of their basis, they at length coalesce at the lower parts. The middle mounds are always the highest, and the largest, and by gradually filling up the intermediate space by the enlargement of the bases of the several mounds, a single mound, with various sugar-loaf-shaped masses of less magnitudes growing out of it, is produced, as shown in fig. 10.

a a a. Turrets by which their hills are raised and enlarged.

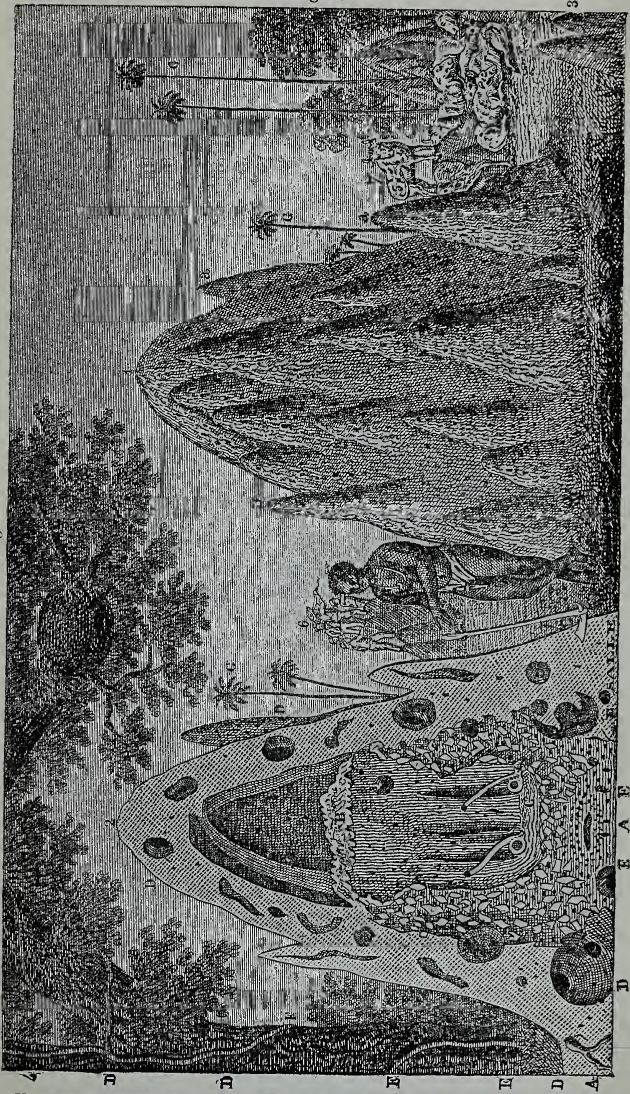
2. A section of 1, as it would appear on being cut down through the middle, from the top to the bottom, a foot lower than the surface of the ground.

A A. An horizontal line from A on the left, and a perpendicular line from A at the bottom will intersect each other at the royal chamber.

The darker shades near it are the empty apartments and passages, which, it seems, are left so for the attendants on the king and queen, who, when old, may require near one hundred thousand to wait on them every day.

The parts which are least shaded and dotted, are the nurseries, surrounded, like the royal chamber, by empty passages on all sides, for the more easy access to them with

Fig. 10.



View of the Habitations of the White Ants, reproduced from the original drawing of Smeathman, engraved in the "Phil. Trans.," vol. lxxi.

the eggs from the queen, the provision for the young, &c. N.B. The magazines of provisions are situated without any seeming order, among the vacant passages which surround the nurseries.

B. The top of the interior building, which often seems, from the arches carried upward, to be adorned on the sides with pinnacles.

C. The floor of the area or nave.

D D D. The large galleries which ascend from under all the buildings spirally to the top.

E E. The bridge.

3. The first appearance of a hill-nest by two turrets.

4. A tree with the nest of the *Termites arborum*, with their covered way.

F F F F. Covered ways of the *Termites arborum.*

5. The nest of the *Termites arborum.*

6. A nest of the *Termites bellicosi*, with Europeans on it.

7. A bull standing sentinel upon one of these nests.

G G G. The African palm-trees from the nuts of which is made the *Oleum palmæ.*

26. When by the accumulation of these turrets the dome has been completed, in which process the turrets supply the place of scaffolding, the workers excavate the interior of them, and make use of the clay in building the partitions and walls of the apartments constructed in the base of the mound which constitutes their proper habitation, and also for erecting fresh turrets surmounting the mound and increasing its height. In this manner the same clay, which, as has been already explained, was excavated from the underground ways issuing around the mound, is used several times over, just as are the posts and boards of a mason's scaffolding.

27. When these mounds have attained a little more than half their height, their tops being then flat, the bulls which are the leaders of the herds of wild cattle which prevail in the surrounding country, are accustomed to mount upon them so as to obtain a view of the surrounding plain: thus placed they act as sentinels for the general herd which feeds and ruminates around them, giving them notice of the approach of any danger. This circumstance supplies an incidental proof of the strength of these structures.

28. Smeathman states that when he was in that country, and desired to obtain a view of the sea to ascertain the approach of vessels, he was in the habit of mounting with three or four of his assistants upon the summits of these conical mounds,

the elevation of which was sufficient to enable him to obtain a satisfactory view.

29. The superior shell or dome by which the mound is surmounted is not only of use to protect the interior buildings from external violence and from the tropical rains, but, from its non-conducting quality, to preserve that uniform temperature within, which is necessary for hatching the eggs and cherishing the young.

30. The royal chamber appropriated to the sovereigns engrosses much of the attention and skill of their industrious subjects. It is generally placed about the centre of the base of the mound, at the level of the surrounding ground, and has the shape of half an egg divided by a plane at right angles to its axis passing a little below its centre. Thus the shape of this chamber is that which architects call a surmounted dome. Its magnitude is proportioned to that of the king and queen to whom it is appropriated. In the infant state of the colony, before the queen is advanced in pregnancy, the diameter of this room does not exceed an inch, but as the royal lady increases in the manner already described, the workers continually enlarge the room, until at length it attains a diameter of eight or nine inches. Its floor is perfectly level, and formed of clay about an inch thick. The roof is formed of a solid well-turned oval arch increasing in thickness from a quarter of an inch at the sides where it rests upon the floor.

31. The doors are cut in the wall, and made of a magnitude suitable to the entrance and exit of the soldiers and workers who attend on the royal pair, but much too small for the passage of the royal personages themselves.

32. This large chamber is surrounded by numerous others of less dimensions, and various shapes, all of which have arched roofs, some circular, and some elliptical. These chambers communicate with each other by doors and corridors. Those which are immediately contiguous to the royal chamber are appropriated to the soldiers, who are in immediate attendance on the sovereign, and to the workers, whose duty it is to supply and attend the royal table, and to carry away the eggs as fast as they are laid by the queen.

33. Around these antechambers is another suite of apartments, consisting of store-rooms for provisions, chambers for the reception of the eggs, and nurseries for the young. The store-rooms are constructed like other parts of the habitation, with walls and partitions of clay, and are always amply supplied with provisions, which, to the naked eye, seem to consist of the raspings of wood and plants, which the workers destroy. Upon submitting them to the microscope, however, they are found to consist prin-

cipally of vegetable gums and inspissated juices. These are thrown together in masses of different appearance, some resembling the sugar on preserved fruits, some transparent, and others opaque, as is commonly seen in all parcels of gum.

The nurseries, on the other hand, are constructed in a manner totally different from the other rooms.

34. The walls and partitions of these consist entirely of wooden materials, cemented together with gum. These nurseries, in which the eggs are hatched, and the young secured, are small irregularly shaped rooms, none of which exceed half an inch in width.

35. When the nest is in the infant state, the nurseries are close to the royal chamber; but as in process of time the queen enlarges, it is necessary to enlarge the chamber for her accommodation; and as she then lays a great number of eggs, and requires a greater number of attendants, so it is necessary also to enlarge and increase the number of the antechambers; for which purpose the small nurseries first built are taken to pieces, rebuilt a little further off a size larger, and their number increased.

36. Thus they continually enlarge their apartments, pull down, repair, or rebuild, according to their wants, with a degree of sagacity, regularity, and foresight, not observed among any other kind of animals or insects.

37. There is one remarkable circumstance attending the nurseries which ought not to be omitted. They are always found slightly overgrown with mould, and plentifully sprinkled with white globules, about the sise of the head of a small pin. These may be at first mistaken for eggs; but submitting them to the microscope, they appear to be a species of mushroom, similar to the common mushroom, of the sort usually pickled. They appear, when whole, white like snow a little thawed and afterwards frozen; and, when bruised, seem to be composed of an infinite number of pellucid particles, having a nearly oval form, and difficult to be separated. The mouldiness seems to be composed of the same kind of substance. The nurseries are enclosed in chambers of clay, like the store-rooms, but much larger. In the early state of the nest, they are not bigger than a hazel-nut, but in large hills are much more spacious.

38. These magazines and nurseries, separated by small empty chambers and galleries, which run round them, or communicate from one to the other, are continued on all sides to the outer wall of the building, and reach up within it to two-thirds or three-fourths of its height. They do not, however, fill up the whole of the lower part of the hill, but are confined to the sides, leaving an open area in the middle, under the dome, very much resem-

bling the nave of an old cathedral, having its roof supported by three or four very large Gothic arches, of which those in the middle of the area are sometimes two and three feet high; but as they recede on each side, rapidly diminish, like the arches of aisles in perspective. A flattish roof, without perforation, in order to keep out the wet, if the dome should chance to be injured, covers the top of the assemblage of chambers, nurseries, &c.; and the area, which is above the royal chambers, has a flattish floor, also water-proof, and so contrived as to let any rain that may chance to get in, run off into the subterraneous passages which run from the basement of the lower apartments through the hill in various directions; and one of astonishing magnitude, often having a bore greater than that of a large piece of ordnance. Smeathman measured the diameter of one of these passages, which was perfectly cylindrical, and found it to be thirteen inches.

39. These subterraneous passages, or galleries, are lined very thick with the same kind of clay of which the hill is composed, and ascend the inside of the outer shell in a spiral manner, and winding round the whole building, up to the top, intersect each other at different heights, opening either immediately into the dome in various places, and into the interior building, the new turrets, &c., or communicating thereto by other galleries of different bores or diameter, either circular or oval.

From every part of these large galleries are various small tunnels or galleries, leading to different parts of the building. Under ground there are many which lead downward, by sloping descents, three or four feet perpendicular, among the gravel, from whence the workers cull the finer parts, which, being worked up in their mouths to the consistence of mortar, become that solid clay of which their hills and all their buildings, except their nurseries, are composed.

40. Other galleries again ascend, and lead out horizontally on every side, and are carried under ground, near to the surface, to a vast distance: for if you destroy all the nests within one hundred yards of your house, the inhabitants of those which are left unmolested farther off will, nevertheless, carry on their subterraneous galleries, and invade the goods and merchandises contained in it by sap and mine, and do great mischief, if you are not very circumspect.

41. But to return to the cities from whence these extraordinary expeditions and operations originate, it seems there is a degree of necessity for the galleries under the hills being thus large, being the great thoroughfares for all the labourers and soldiers going forth or returning upon any business whatever, whether

fetching clay, wood, water, or provisions; and they are certainly well calculated for the purposes to which they are applied, by the spiral slope which is given them; for if they were perpendicular, the labourers would not be able to carry on their building with so much facility, since they cannot ascend a perpendicular without great difficulty, and the soldiers can scarcely do it at all. It is on this account that sometimes a road, like a ledge, is made on the perpendicular side of part of the building within their hill, which is flat on the upper surface, and half an inch wide, and ascends gradually like a staircase, or like those roads which are cut on the sides of hills and mountains, that would otherwise be inaccessible; by which, and similar contrivances, they travel with great facility to every interior part.

42. This too is probably the cause of their building a kind of bridge of one vast arch, which answers the purpose of a flight of stairs from the floor of the area to some opening on the side of one of the columns which support the great arches. Such bridges shorten the distance considerably to those labourers who have the eggs to carry from the royal chamber to some of the upper nurseries, which in some hills would be four or five feet in the straightest line, and much more if carried through all the winding passages which lead through the inner chambers and apartments.

Smeathman found one of these bridges half an inch broad, a quarter of an inch thick, and ten inches long, making the side of an elliptic arch of proportional size; so that it is wonderful it did not fall over or break by its own weight before they got it joined to the side of the column above. It was strengthened by a small arch at the bottom, and had a hollow or groove all the length of the upper surface, either made purposely for the inhabitants to travel over with more safety, or else, which is not improbable, worn so by frequent treading.

43. "Consider," observes Kirby, "what incredible labour and diligence, accompanied by the most unremitting activity and the most unwearied celerity of movement, must be necessary to enable these creatures to accomplish, their size considered, these truly gigantic works. That such diminutive insects, for they are scarcely the fourth of an inch in length, however numerous, should, in the space of three or four years, be able to erect a building twelve feet high, and of a proportionable bulk, covered by a vast dome, adorned without by numerous pinnacles and turrets, and sheltering under its ample arch myriads of vaulted apartments of various dimensions, and constructed of different materials —that they should moreover excavate, in different directions, and at different depths, innumerable subterranean roads or tunnels,

some twelve or thirteen inches in diameter, or throw an arch of stone over other roads leading from the metropolis into the adjoining country to the distance of several hundred feet—that they should project and finish the, for them, vast interior staircases or bridges lately described—and, finally, that the millions necessary to execute such Herculean labours, perpetually passing to and fro, should never interrupt or interfere with each other, is a miracle of nature, or rather of the Author of nature, far exceeding the most boasted works and structures of man: for, did these creatures equal him in size, retaining their usual instincts and activity, their buildings would soar to the astonishing height of more than half a mile, and their tunnels would expand to a magnificent cylinder of more than three hundred feet in diameter; before which the pyramids of Egypt and the aqueducts of Rome would lose all their celebrity, and dwindle into nothings.

"The most elevated of the pyramids of Egypt is not more than 600 feet high, which, setting the average height of man at only five feet, is not more than 120 times the height of the workmen employed. Whereas the nests of the Termites being at least twelve feet high, and the insects themselves not exceeding a quarter of an inch in stature, their edifice is upwards of 500 times the height of the builders; which, supposing them of human dimensions, would be more than half a mile. The shaft of the Roman aqueducts was lofty enough to permit a man on horseback to travel in them." *

44. The bodies of the Termites are generally soft and covered with a thin and delicate skin, and being blind, they are no match on the open ground for the ants who are endowed with vision, and whose bodies are invested in a strong horny shell. Whenever the Termites are accidentally dislodged from their subterraneous roads or dwellings, the various species of ants instantly seize them and drag them away to their nests as food for their young.

45. The Termites are therefore very solicitous about preserving their tunnels and vaulted roads in good repair. If some of them be accidentally demolished for a few inches in length, it is wonderful how speedily they rebuild it. At first, in their hurry, they advance into the open part for an inch or two, but stop so suddenly that it is very apparent that they are surprised, for although some run straight on until they get under the arch beyond the damaged part, most of them run as fast back, and very few of them will venture through that part of the track which is left uncovered. In a few minutes, however, they will be seen rebuilding the arch, and even if three or four yards in length have been destroyed, they will reconstruct it in a single day. If this be again destroyed,

* Kirby, vol. i. p. 434.

they will be seen as numerous as ever passing both ways along it, and they will again in like manner reconstruct it. But if the same part be destroyed several times successively, they will give up the point and build a new covered way in another direction. Nevertheless, if the old one should lead to some favourite source of plunder, they will, after a few days' interval, still reconstruct it, apparently in the hope that the cause of destruction will not again occur, nor will they in that case wholly abandon the undertaking unless their habitation itself be destroyed.

Fig. 5.—Worker.

Fig. 6.—Soldier.

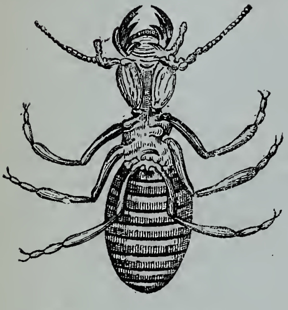


Fig. 7.—Worker, magnified.

Fig. 8.—Forceps of Soldier, magnified.

THE WHITE ANTS,

THEIR MANNERS AND HABITS.

CHAPTER II.

46. Turrets built by the Termes mordax and the Termes atrox.—47. Description of their structure.—48. Their king, queen, worker, and soldier.—49. Internal structure of their habitation.—50. Nests of the Termes arborum.—51. Process of their construction.—52. Hill nests on the Savannahs.—53. The Termes lucifugus—the organisation cf their societies.—54. Habits of the workers and soldiers—the materials they use for building.—55. Their construction of tunnels.—56. Nests of the Termes arborum in the roofs of houses.—57. Destructive habits of the Termes bellicosus in excavating all species of wood-work—entire houses destroyed by them.—58. Curious process by which they fill with mortar the excavations which they make—destruction of Mr. Smeathman's microscope.—59. Destruction of shelves and wainscoting.—60. Their artful process to escape observation.—61. Anecdotes of them by Kœmpfer and Humboldt.—62. Destruction of the Governor's house at Calcutta—destruction by them of a British ship of the line.—63. Their manner of attacking timber in the open air—their wonderful power of destroying fallen timber.—64. The extraordinary behaviour of the soldiers when a nest is attacked.

65. Their rage and fury against those who attack them.—66. Their industry and promptitude in repairing the damage of their habitation.—67. The vigilance of the soldiers during the process of repair.—68. Effects of a second attack on their habitation, conduct of the soldiers.—69. Difficulty of investigating the structure of their habitations—obstinate opposition of the soldiers—discovery of the royal chamber—fidelity of the subjects to the sovereign—curious experiment of Mr. Smeathman.—70. Curious example of the repair of a partially destroyed nest.—71. The marching Termites—curious observation of their proceedings by Smeathman—remarkable conduct of the soldiers on the occasion.

46. A smaller species of Termites erect habitations, which, if they are of less dimensions, are not less curious in their structure.

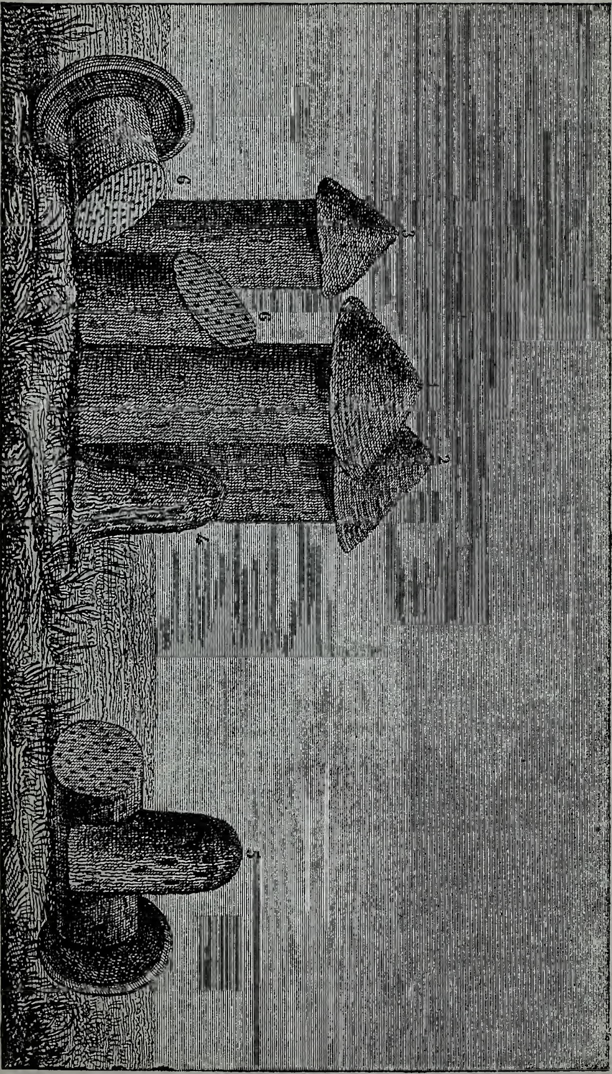
These buildings are upright cylinders, composed of a well-tempered black earth or clay, about three quarters of a yard high, and covered with a roof of the same material in the shape of a cone, whose base extends over and hangs down three or four inches wider than the perpendicular sides of the cylinder, so that most of them resemble in shape a round windmill, or still more closely the round towers which are so frequently seen in Ireland, and which have attracted so much attention on the part of antiquaries. Some of these roofs have so little elevation in the centre, that they have a close resemblance to certain species of mushroom.

After one of these turrets is finished, it is not altered or enlarged; but when no longer capable of containing the community, the foundation of another is laid within a few inches of it. Sometimes, though but rarely, the second is begun before the first is finished, and a third before they have completed the second: thus they will run up five or six of these turrets at the foot of a tree in the thick woods, and make a most singular group of buildings, as shown in fig. 11.

1 Nest of the *Termes mordax.*
2 Nest of the *Termes atrox.*
3 A turret with the roof begun.
4 A turret raised only about half its height.
5 A turret built upon one which has been thrown down.
6 6 A turret broken in two.

47. The turrets are so strongly built, that in case of violence they will much sooner overset from the foundations, and tear up the ground and solid earth, than break in the middle; and in that case the insects will frequently begin another turret and build it, as it were, through that which has fallen; for they will connect the cylinder below with the ground, and run up a new turret from its upper side, so that it will seem to rest upon the horizontal cylinder only.

Fig. 11.



The Turret Nests of the Termes Mordax and Termes Atrox.

48. In fig. 12 is represented the king or queen of the *Termes mordax*, in fig. 13 the worker, and in fig. 14 the soldier.

TERMES MORDAX.

Fig. 12.

King or Queen.

Fig. 13.

Worker.

Fig. 14.

Soldier.

The building is divided into innumerable cells of irregular shapes; sometimes they are quadrangular or cubic, and sometimes pentagonal; but often the angles are so ill defined, that each half of a cell will be shaped like the inside of that shell which is called the sea-car.

49. Each cell has two or more entrances, but as there are no tunnels or galleries, no variety of apartments, no well-turned arches, wooden nurseries, &c., &c., as in the habitations already described, they are not calculated to excite the same degree of wonder, however admirable they may be considered without reference to other structures.

There are two sizes of these turret nests, built by two different species of Termites. The larger species, the *Termes atrox*, in its perfect state, measures one inch and three-tenths from the extremities of the wings on the one side to the extremities on the other. The lesser, *Termes mordax*, measures only eight-tenths of an inch from tip to tip.

50. The next kind of nests, built by another species of this genus, the *Termes arborum*, have very little resemblance to the former in shape or substance. These are generally spherical or oval, built in trees: sometimes they are established between, and sometimes surrounding, the branches, at the height of seventy or eighty feet; and are occasionally as large as a great sugar-cask.

51. They are composed of small particles of wood and the various gums and juices of trees, combined with, perhaps, those secreted by the animals themselves, worked by those little industrious creatures into a paste, and so moulded into innumerable little cells of different and irregular forms. These nests, with the immense quantity of inhabitants, young and old, with which they are at all times crowded, are used as food for young fowls, and especially for the rearing of Turkeys. These nests are very compact, and so strongly fixed to the boughs, that there is no detaching them but by cutting them in pieces, or sawing off the branch. They will even sustain the force of a tornado as long as the tree to

which they are attached. This species has the external habit, size, and almost the colour, of the *Termes atrox.*

52. There are some nests that resemble the hill-nests first described, built in those sandy plains called Savannahs. They are composed of black mud, raised from a few inches below the white sand, and are built in the form of an imperfect or bell-shaped cone, having their tops rounded. These are generally about four or five feet high. They seem to be inhabited by insects nearly as large as the *Termes bellicosus*, and differing very little from that species, except in colour, which is brighter.

53. The societies of *Termes lucifugus*, discovered by Latreille at Bourdeaux, are very numerous; but instead of making artificial nests, they make their lodgments in the trunks of pines and oaks, where the branches diverge from the tree. They eat the wood the nearest the bark without attacking the interior, and bore a vast number of holes and irregular galleries. That part of the wood appears moist, and is covered with little gelatinous particles, not unlike gum-arabic. These insects seem to be furnished with an acid of a very penetrating odour, which, perhaps, is useful to them in softening the wood. The soldiers in those societies are as about one to twenty-five of the labourers.

The anonymous author of the Observations on the Termites of Ceylon, seems to have discovered a sentry-box in his nests. "I found," says he, "in a very small cell in the middle of the solid mass, (a cell about half an inch in height, and very narrow,) a larva with an enormous head. Two of these individuals were in the same cell; one of the two seemed placed as sentinel at the entrance of the cell. I amused myself by forcing the door two or three times; the sentinel immediately appeared, and only retreated when the door was on the point to be stopped up, which was done in three minutes by the labourers."

54. Having thus given some idea of their habitations, we shall now direct our observations to the insects themselves, their manner of building, fighting, and marching, and to a more particular account of the vast mischief they cause to mankind.

It is a common character of the different species which have been noticed, that the workers and the soldiers never expose themselves in the open air, but invariably travel either under ground, or along the holes which they bore in trees and other substances. When in certain exceptional cases in quest of plunder they are compelled to move above ground, they make a vault with a coping of earth, or a tube, formed of that material with which they build their nests, along which they travel completely protected. The *Termes bellicosus* uses for this purpose the red, and the turret-builders black clay; whilst the *Termes* *arborum* employs for the purpose the ligneous substances of which their nests are composed.

55. With these materials they completely line most of the roads leading from their nests into the various parts of the country, and travel out and home with the utmost security in all kinds of weather. If they meet a rock or any other obstruction, they will make their way upon the surface, and for that purpose erect a covered way or arch, still of the same materials, continuing it with many windings and ramifications through large grooves, having, where it is possible, subterranean pipes running parallel with them, into which they sink, and save themselves, if their galleries above ground are destroyed by any violence, or the tread of men or animals alarms them. When any one chances by accident to enter any solitary grove, where the ground is pretty well covered with their arched galleries, they give the alarm by loud hissings, which he hears distinctly at every step he makes; soon after which he may examine their galleries in vain for the insects, which escape through little holes, just large enough for them, into their subterraneous roads. These galleries are large enough for them to pass and repass, so as to prevent any stoppages, and shelter them equally from light and air, as well as from their enemies, of which the ants, being the most numerous, are the most formidable.

56. The *Termites arborum*, those which build in trees, frequently establish their nests within the roofs and other parts of houses, to which they do considerable damage if not extirpated.

57. The larger species are, however, not only much more destructive, but more difficult to be guarded against, since they make their approaches chiefly under ground, descending below the foundations of houses and stores at several feet from the surface, and rising again either in the floors, or entering at the bottoms of the posts, of which the sides of the buildings are composed, bore quite through them, following the course of the fibres to the top, or making lateral perforations and cavities here and there as they proceed.

While some are employed in gutting the posts, others ascend from them, entering a rafter or some other part of the roof. If they once find the thatch, which seems to be a favourite food, they soon bring up wet clay, and build their pipes or galleries through the roof in various directions, as long as it will support them, sometimes eating the palm-tree leaves and branches of which it is composed, and perhaps (for variety seems very pleasing to them) the rattan or other running plant which is used as a cord to tie the various parts of the roof together, and to the posts which support it; thus, with the assistance of the rats, who, during the rainy season, are apt to shelter themselves there, and to burrow through it, they very soon ruin the house by weakening the fastenings and exposing it to the wet. In the meantime, the posts will be perforated in every direction, as full of holes as that timber in the bottom of ships which has been bored by the worms; the fibrous and knotty parts, which are the hardest, being left to the last.

58. They sometimes, in carrying on this business, find that the post has some weight to support, and then, if it is a convenient track to the roof, or is itself a kind of wood agreeable to them, they bring their mortar, and fill all or most of the cavities, leaving the necessary roads through it, and as fast as they take away the wood, replace the vacancy with that material; which being worked together by them closer and more compactly than human strength or art could ram it, when the house is pulled to pieces, in order to examine if any of the posts are fit to be used again, those of the softer kinds are often found reduced almost to a shell, and all, or a greater part, transformed from wood to clay, as solid and as hard as many kinds of freestone used for building in England.

It is much the same when the *Termites bellicosi* get into a chest or trunk containing clothes and other things; if the weight above is great, or they are afraid of ants and other enemies, and have time, they carry their pipes through, and replace a great part with clay, running their galleries in various directions. The tree-Termites, indeed, when they get within a box, often make a nest there, and being once in possession destroy it at their leisure. They did so in a pyramidal box which contained the compound microscope of Mr. Smeathman. It was of mahogany, and he deposited it in the warehouse of Governor Campbell of Tobago, while he made a tour of a few months in the Leeward Islands. On his return he found that the Termites had done much mischief in the warehouse, and, among other things, had taken possession of the microscope, and eaten everything about it except the glass or metal, including the board on which the pedestal is fixed, with the drawers under it, and the things enclosed. The cells were built all round the pedestal and the tube, and attached to it on every side. All the glasses were covered with the wooden substance of their nests, and retained a cloud of a gummy nature upon them which was not easily got off, and the lacquer or burnish with which the brasswork was covered was totally spoiled.

Another party had taken a liking to a cask of Madeira, and had bored so as to discharge almost a pipe of fine old wine. If the large species of Africa (the *Termites bellicosi*) had been so long in the uninterrupted possession of such a warehouse, they would not have left twenty pounds weight of wood remaining of the whole building, and all that it contained.

59. These insects are not less expeditious in destroying the shelves, wainscotting, and other fixtures of a house, than the house itself. They are for ever piercing and boring in all directions, and sometimes go out of the broadside of one post into that of another joining to it; but they prefer, and always destroy the softer substances the first, and are particularly fond of pine and fir-boards, which they excavate and carry away with wonderful despatch and astonishing cunning; for, unless a shelf has something standing upon it, as a book, or anything else which may tempt them, they will not perforate the surface, but artfully preserve it quite whole, and eat away all the inside, except a few fibres which barely keep the two sides connected together, so that a piece of an inch board which appears solid to the eye will not weigh much more than two sheets of pasteboard of equal dimensions, after these animals have been a little while in possession of it.

60. In short the Termites are so insidious in their attacks, that we cannot be too much on our guard against them: they will sometimes begin and raise their works, especially in new houses, through the floor. If you destroy the work so begun, and make a fire upon the spot, the next night they will attempt to rise through another part; and, if they happen to emerge under a chest or trunk early in the night, will pierce the bottom, and destroy or spoil everything in it before morning. On these accounts care is taken by the inhabitants of the country to set all their chests and boxes upon stones or bricks, so as to leave the bottoms of such furniture some inches above the ground; which not only prevents these insects finding them out so readily, but preserves the bottoms from a corrosive damp which would strike from the earth through, and rot everything therein; a vast deal of vermin would also harbour under, such as cockroaches, centipedes, millepedes, scorpions, ants, and various other noisome insects.

61. Kœmpfer, speaking of the white ants of Japan, gives a remarkable instance of the rapidity with which these miners proceed. Upon rising one morning, he observed that one of their galleries, of the thickness of his little finger, had been formed across his table; and upon a further examination he found that they had bored a passage of that thickness up one foot of the table, formed a gallery across it, and then pierced down another foot into the floor; all this was done in the few hours that intervened between his retiring to rest and his rising. They make

their way also with the greatest ease into trunks and boxes, even though made of mahogany, and destroy papers and everything they contain, constructing their galleries and sometimes taking up their abode in them. Hence, as Humboldt informs us, throughout all the warmer parts of equinoctial America, where these and other destructive insects abound, it is infinitely rare to find papers which go fifty or sixty years back. In one night they will devour all the boots and shoes that are left in their way; cloth, linen, or books are equally to their taste; but they will not eat cotton. They entirely consumed a collection of insects made in India. In a word, scarcely anything but metal or stones comes amiss to them.

62. It is even asserted that the superb residence of the Governor-General at Calcutta, which cost the East India Company such immense sums, is now rapidly going to decay in consequence of the attacks of these insects. But not content with the dominions they have acquired, and the cities they have laid low on terra firma, encouraged by success, the white ants have also aimed at the sovereignty of the ocean, and once had the hardihood to attack even a British ship of the line; and in spite of the efforts of the commander and his valiant crew, having boarded they got possession of her, and handled her so roughly, that when brought into port, being no longer fit for service, she was obliged to be broken up.

The ship here alluded to was the Albion, which was in such a condition from the attack of these insects, that had it not been firmly lashed together, it was thought she would have foundered on her voyage home. The late Mr. Kittoe stated that the *droguers* or *draguers*, a kind of lighter employed in the West Indies in collecting the sugar, sometimes so swarm with ants of the common kind, that they have no other way of getting rid of these troublesome insects than by sinking the vessel in shallow water.

63. When the Termites attack trees and branches in the open air, they sometimes vary their manner of doing it. If a stake in a hedge has not taken root and vegetated, it becomes their business to destroy it. If it has a good sound bark round it, they will enter at the bottom, and eat all but the bark, which will remain, and exhibit the appearance of a solid stick (which some vagrant colony of ants or other insects often shelter in, till the winds disperse it); but if they cannot trust the bark, they cover the whole stick with their mortar, and it then looks as if it had been dipped into thick mud that had been dried on. Under this covering they work, leaving no more of the stick and bark than is barely sufficient to support it, and frequently not the smallest particle, so that upon a very small tap with your walking stick,

the whole stake, though apparently as thick as your arm, and five or six feet long, loses its form, and, disappearing like a shadow, falls in small fragments at your feet. They generally enter the body of a large tree which has fallen through age, or been thrown down by violence, on the side next the ground, and eat away at their leisure within the bark, without giving themselves the trouble either to cover it on the outside, or to replace the wood which they have removed from within, being somehow sensible that there is no necessity for it. "Such excavated trees," says Mr. Smeathman, "deceived me two or three times in running; for, attempting to step two or three feet high, I might as well have attempted to step upon a cloud, and have come down with such unexpected violence, that, besides shaking my teeth and bones almost to dislocation, I have been precipitated head foremost among the neighbouring trees and bushes." Sometimes, though seldom, the animals are known to attack living trees; but not before symptoms of mortification have appeared at the roots; since it is evident that these insects are intended in the order of nature to hasten the dissolution of such trees and vegetables as have arrived at their greatest maturity and perfection, and which would, by a tedious decay, serve only to encumber the face of the earth. This purpose they answer so effectually that nothing perishable escapes them, and it is almost impossible to leave anything penetrable upon the ground a long time in safety; for the odds are, put it where you will abroad, they will find it out before the following morning, and its destruction follows very soon of course. In consequence of this disposition, the woods never remain long encumbered with the fallen trunks of trees or their branches; and thus it is that the total destruction of deserted towns is so effectually completed, that in two or three years a thick wood fills the space; and, unless *iron-wood* posts have been made use of, not the least vestige of a house is to be discovered.

64. The first object of admiration, which strikes one upon opening their hills, is the behaviour of their soldiers. If you make a breach in a slight part of the building, and do it quickly, with a strong hoe or pick-axe, in the space of a few seconds a soldier will run out, and walk about the breach, as if to see whether the enemy is gone, or to examine what is the cause of the attack. He will sometimes go in again, as if to give the alarm; but most frequently, in a short time, is followed by two or three others, who run as fast as they can, straggling after one another, and are soon followed by a large body, who rush out as fast as the breach will permit them, and so they proceed, the number increasing, as long as any one continues battering their building. It is not easy to describe the rage and fury they show.

In their hurry they frequently miss their hold, and tumble down the sides of the hill, but recover themselves as quickly as possible; and being blind, bite everything they run against, and thus make a crackling noise, while some of them beat repeatedly with their forceps upon the building, and make a small vibrating noise, something shriller and quicker than the ticking of a watch. This noise can be distinguished at three or four feet distance, and continues for a minute at a time, with short intervals. While the attack proceeds, they are in the most violent bustle and agitation.

65. If they get hold of any one they will, in an instant, let out blood enough to weigh against their whole body; and if it is the leg they wound, you will see the stain upon the stocking extend an inch in width. They make their hooked jaws meet at the first stroke, and never quit their hold, but suffer themselves to be pulled away leg by leg, and piece after piece, without the least attempt to escape. On the other hand, keep out of their way, and give them no interruption, and they will, in less than half an hour, retire into the nest, as if they supposed the wonderful monster that damaged their castle to be gone beyond their reach.

66. Before they are all got in, you will see the labourers in motion, and hastening in various directions towards the breach; every one with a burthen of mortar in his mouth ready tempered. This they stick upon the breach as fast as they come up, and do it with so much dispatch and facility, that although there are thousands, and even millions of them, they never stop or embarrass one another; and you are most agreeably deceived when, after an apparent scene of hurry and confusion, a regular wall arises, gradually filling up the chasm. While they are thus employed, almost all the soldiers are retired quite out of sight, except here and there one, who saunters about among six hundred or a thousand of the labourers, but never touches the mortar either to lift or carry it; one, in particular, places himself close to the wall they are building.

67. This soldier will turn himself leisurely on all sides, and every now and then, at intervals of a minute or two, lift up his head, and with his forceps beat upon the building, and make the vibrating noise before mentioned; on which immediately a loud hiss, which appears to come from all the labourers, issues from within side the dome, and all the subterraneous caverns and passages: that it does come from the labourers is very evident, for you will see them all hasten at every such signal, redouble their pace, and work as fast again.

68. As the most interesting experiments become dull by repe-

tition or continuance, so the uniformity with which this business is carried on, though so very wonderful, at last satiates the mind. A renewal of the attack, however, instantly changes the scene, and gratifies our curiosity still more. At every stroke we hear a loud hiss; and on the first the labourers run into the many pipes and galleries with which the building is perforated, which they do so quickly that they seem to vanish, for in a few seconds all are gone, and the soldiers rush out as numerous and as vindictive as before. On finding no enemy they return again leisurely into the hill, and very soon after the labourers appear loaded as at first, as active and as sedulous, with soldiers here and there among them, who act just in the same manner, one or other of them giving the signal to hasten the business. Thus the pleasure of seeing them come out to fight or to work alternately may be obtained as often as curiosity excites or time permits; and it will certainly be found, that the one order never attempts to fight, or the other to work, let the emergency be ever so great.

69. We meet vast obstacles in examining the interior parts of these tumuli. In the first place the works, for instance, the apartments which surround the royal chamber and the nurseries, and indeed the whole internal fabric, are moist, and consequently the clay is very brittle; they have also so close a connection, that they can only be seen as it were by piecemeal; for having a kind of geometrical dependence or abutment against each other, the breaking of one arch pulls down two or three. To these obstacles must be added the obstinacy of the soldiers, who fight to the very last, disputing every inch of ground so well as often to drive away the negroes who are without shoes, and make white people bleed plentifully through their stockings. Neither can we let a building stand, so as to get a view of the interior parts without interruption, for while the soldiers are defending the outworks, the labourers keep barricading all the way against us, stopping up the different galleries and passages, which lead to the various apartments, particularly the royal chamber, all the entrances to which they fill up so artfully as not to let it be distinguishable, while it remains moist; and externally it has no other appearance than that of a shapeless lump of clay. It is, however, easily found from its situation with respect to the other parts of the building, and by the crowds of labourers and soldiers which surround it, who show their loyalty and fidelity by dying under its walls. The royal chamber, in a large nest, is capacious enough to hold many hundreds of the attendants, besides the royal pair, and you always find it as full of them as it can hold. These faithful subjects never abandon their charge, even in the last distress, for whenever Mr. Smeathman took out the royal

chamber from one of the hills, as he often did, and preserved it for some time in a large glass bowl, all the attendants continued running in one direction round the king and queen with the utmost solicitude, some of them stopping in every circuit at the head of the latter, as if to give her something; when they came to the extremity of the abdomen, they took the eggs from her, carrying them away, and piled them carefully together in some part of the chamber, or in the bowl under, or behind any pieces of broken clay, which lay most convenient for the purpose.

Some of these unhappy little creatures would ramble from the chamber as if to explore the cause of such a horrid ruin and catastrophe to their immense buildings, as it must appear to them; and after fruitless endeavours to get over the side of the bowl, return and mix with the crowd that continued running round their common parents to the last. Others, placing themselves along her side, would get hold of the queen's vast matrix with their jaws, and pull with all their strength, so as visibly to lift up the part which they fix at; but Mr. Smeathman who observed this, was unable to determine whether this pulling was with an intention to remove her body, or to stimulate her to move herself, or for any other purpose. After many ineffectual tugs, they would desist and join in the crowd running round, or assist some of those who are cutting off clay from the external parts of the chamber, or some of the fragments, and moistening it with the juices of their bodies, to begin to work a thin arched shell over the body of the queen, as if to exclude the air, or to hide her from the observation of some enemy. These, if not interrupted, before the next morning, completely cover her, leaving room enough within for great numbers to run about her.

The king, being very small in proportion to the queen, generally conceals himself under one side of her abdomen, except when he goes up to the queen's head, which he does now and then, but not so frequently as the rest.

70. If in your attack on the hill you stop short of the royal chamber, and cut down about half of the building, and leave open some thousands of galleries and chambers, they will all be shut up with thin sheets of clay before next morning. If even the whole is pulled down, and the different buildings are thrown in a confused heap of ruins, provided the king and queen are not destroyed or taken away, every interstice between the ruins, at which either cold or wet can possibly enter, will be so covered as to exclude both; and, if the animals are left undisturbed, in about a year they will raise the building to near its pristine size and grandeur.

71. The marching Termites are not less curious in their order

than those described before. This species seems much scarcer and larger than the *Termes bellicosus*. They are little known to the natives. Smeathman had an opportunity of observing them by mere accident; one day, having made an excursion with his gun up the river Camcrankoes, on his return through the thick forest, while he was sauntering very silently in hopes of finding some sport, on a sudden he heard a loud hiss, which, on account of the many serpents in these countries, is a most alarming sound. The next step caused a repetition of the noise, which he soon recognised, and was rather surprised, seeing no covered ways or hills. The noise, however, led him a few paces from the path, where, to his great astonishment and pleasure, he saw an army of Termites coming out of a hole in the ground, which could not be above four or five inches wide. They came out in vast numbers, moving forward as fast seemingly as it was possible for them to march. In less than a yard from this place they divided into two streams or columns, composed chiefly of labourers, twelve or fifteen abreast, and crowded as close after one another as sheep in a drove, going straight forward, without deviating to the right or the left. Among these, here and there, one of the soldiers was to be seen, trudging along with them in the same manner, neither stopping nor turning; and as he carried his enormous large head with apparent difficulty, he appeared like a very large ox amongst a flock of sheep. While these were bustling along, a great many soldiers were to be seen spread about on both sides of the two lines of march, some a foot or two distant, standing still or sauntering about as if upon the look-out lest some enemy should suddenly come upon the workers. But the most extraordinary part of this march was the conduct of some others of the soldiers, who, having mounted the plants which grow thinly here and there in the thick shade, had placed themselves upon the points of the leaves, which were elevated ten or fifteen inches above the ground, and hung over the army marching below. Every now and then one or other of them beat with his forceps upon the leaf, and made the same sort of ticking noise, which he had so frequently observed to be made by the soldier who acts the part of surveyor or superintendent, when the labourers are at work repairing a breach made in one of the common hills of the *Termites bellicosi*. This signal among the marching white ants produced a similar effect; for whenever it was made, the whole army returned a hiss, and obeyed the signal by increasing their pace with the utmost hurry. The soldiers who had mounted aloft, and gave these signals, sat quite still during the interval (except making now and then a slight turn of the head), and seemed as solicitous to keep their posts as regular sentinels. The two columns of the army joined into one about twelve or fifteen paces from their separation, having in no part been above three yards asunder, and then descended into the earth by two or three holes. They continued marching by him for above an hour that he stood admiring them, and seemed neither to increase nor diminish their numbers, the soldiers only excepted, who quitted the line of march, and placed themselves at different distances on each side of the two columns; for they appeared much more numerous before he quitted the spot. Not expecting to see any change in their march, and being pinched for time, the tide being nearly up, and his departure being fixed at high-water, he quitted the scene with some regret, as the observation of a day or two might have afforded him the opportunity of exploring the reason and necessity of their marching with such expedition, as well as of discovering their chief settlement, which is probably built in the same manner as the large hills before described. If so, it may be larger and more curious, as these insects were at least one-third larger than the other species, and consequently their buildings must be more wonderful, if possible; thus much is certain, there must be some fixed place for their king and queen, and the young ones. Of these species he did not see the perfect insect.

In fine, although the curious and interesting habits and manners which have been here described have been well ascertained and accurately observed, naturalists are not yet agreed as to the true physiological characters of the most numerous of the classes composing these communities. That the two individuals called the king and queen in the preceding pages, are perfect insects, deprived of their wings, seems to be on all hands admitted; and that they are kept for the special purpose of propagation, and honoured as the common parents, is also certain. But the true character of the multitude of workers and soldiers is not so clear. Latreille inferred that the workers of Smeathman consist of the larvæ and pupæ, which later pass into the perfect state, assuming wings, and swarm in the manner already described; and that the soldiers are an order apart, which never assume the perfect state, and are incapable of reproduction. To this, Burmeister objects, that there is no instance in the whole animal world in which the undeveloped young labour for the old; and therefore doubts that the workers can be larvæ or pupæ; to which may be added, that these so-called larvæ still retain their form when the winged individuals appear. Huber also doubts that the soldiers can be properly called neuters, and Kirby thinks they are probably male larvæ. Westwood suggests that the soldiers as well as the workers remain wingless without changing their form, their development stopping short before arriving at maturity, and thereby some individuals acquire that enlarged head which distinguishes the soldiers, and that the real larvæ of the comparatively few specimens which ultimately become winged, are as yet unknown.

These vague and discordant conjectures of naturalists so eminent, show how much still remains to be discovered of the physiology of the White Ants.

I.—UNITED KINGDOM, DENMARK, &C.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER I.

THE SURFACE OF THE EARTH : 1. Origin of the name.—2. Preliminary knowledge.—3. The distribution of land and water.—4. The undulations of the terrestrial surface.—5. GEOGRAPHICAL TERMS : 6. Islands.—7. Continents.—8. Peninsulas.—9. Isthmuses.—10. Promontories.—11. Capes and headlands.—12. The relief of the land.—13. Plains and lowlands.—14. Plateaux and table-lands.—15. Hills.—16. Mountains.—17. Systems or chains of mountains.—18. Oceans.—19. Seas.—20. Gulfs.—21. Bays.—22. Straits.—23. Channels.—24. Roads and roadsteads.—25. Banks and sand-banks.—26. Reefs.—27. Soundings.—28. Lakes.—29. Rivers.—30. The bed of a river.—31. The banks of a river.—32. Tributaries.—33. Vallies.—34. Watersheds.—35. Delta.—36. Estuaries.—37. Friths. THE GREAT EASTERN CONTINENT : 38. Its extent and limits.—39. Its divisions. 40. The Mediterranean.—41. Relief.—42. Its northern belt.—43. The southern belt.—44. Prevailing mountain chains.—45. Outlines of Europe.—46. White Sea.—47. Norway and Sweden.—48. British Isles.—49. France.—50. Spain and Portugal.—51. Italy.—52. Sicily.—53. Greece.—54. Archipelago.—55. Dardanelles and Bosphorus.—56. The Black Sea.—57. Sea of Azof.—58. The Caspian.

—59. Africa.—60. Its climatological zones.—61. The Tell and Sahara.—62. Valley of the Nile.—63. The central belt.—64. The fourth zone.—65. The southern zone.—66. The coasts.

1. **Origin of the name.**—The division of general instruction to which the description of the surface of the earth has been consigned, is called *Geography*, from two Greek words γῆ (ge) the earth, and γράφω (grapho) I describe.

2. **Preliminary knowledge.**—The globular form of the earth,—its rotation every twenty-four hours on its axis,—its poles and equator, the imaginary lines upon it called meridians and parallels,—latitudes and longitudes by which the positions of places relatively to the equator and to each other are expressed,—the methods of ascertaining these positions for all places,—the division of the globe into the northern and southern hemispheres by the equator, and into the eastern and western hemispheres by the meridian of Greenwich,—have been severally explained in our Tracts on the "Earth" and on "Latitudes and Longitudes." All these points constitute indispensable preliminaries to any clear or satisfactory knowledge of geography, and we shall therefore assume in the present Tract that the reader has already become familiar with them.

3. **The distribution of land and water** on the surface of the globe forms the first step in geographical knowledge. The entire terrestrial surface measures about two hundred millions of square miles. Very nearly three-fourths of this is covered with water. The whole surface would be so if it were uniformly level. But being unequal, some parts being more elevated, and others less so, the water, in obedience to the law of gravity, settles upon the lower levels, leaving the more elevated parts dry. It is thus that the Almighty has "gathered the waters into one place," and made "the dry land appear," and to the "gathering of waters" has given the name *Seas*.

Land is therefore nothing more than the summits and elevated plateaux of vast mountains, the bases of which are at the bottom of the water which thus covers three-fourths of the surface.

4. **The undulations of the terrestrial surface** are extremely diversified and irregular, and since the distribution and outlines of the land are determined by them, the latter are equally various and complicated. The declivities by which these elevated parts slope downwards, determine the lines according to which the waters of the sea wash them, and these outlines give those peculiar forms and characters to the land, the description and knowledge of which forms a large part of geography. A system of terms has been invented by which these various forms are expressed and classified.

5. **Geographical Terms.**—Although these terms do not always admit of rigorous definition, and their application is often more or less arbitrary, they are nevertheless eminently useful, and indeed essential to the acquisition of a general knowledge of geography.

6. **Islands** are tracts of land surrounded by water. The term, however, is generally limited to tracts of not very considerable extent. When very small they are often called *isles* or *islets.*

The distribution of islands is not uniform. In some parts they are thickly clustered together within a limited extent of water. A part of the sea thus sprinkled with islands is called an archipelago,* a name which was first applied to the Ægæan Sea, which separates Greece from Asia Minor, but which has been generalised so as to signify any portion of the waters of the globe having a like character.

Islands are found for the most part in the immediate vicinity of the coasts of much larger tracts of land. In this case they are evidently parts of such tracts, separated from them only by valleys, so low that the sea flows through them. Islands, however, are also sometimes found in groups, sometimes ranged in lines, and sometimes, though not frequently, rising singly and isolated in the midst of the ocean.

7. **Continents** are tracts surrounded by water, whose magnitude bears a considerable proportion to the entire surface of the globe.

It will be easily understood that this distinction between islands and continents, depending only on their comparative magnitudes, must be arbitrary, so long as no exact limit is assigned at which a tract of land surrounded by water ceases to be an island and becomes a continent.

The tract in the southern hemisphere, called *Australia*, was formerly classed as an island. More recently geographers give it the title of a continent.

Besides this, there are only two continents properly so called on the globe, each of which has vast magnitude, the one lying in the eastern, and the other in the western hemisphere.

The Eastern Continent, sometimes called the *great continent,* includes Europe, Asia, and Africa, each of which has received the name of continent, though the whole forms one continuous tract of land, between any two points of which it is possible to pass without crossing a sea.

* Etymologists are not agreed upon the origin of this term ; some supposing it to be composed of ἀρχὸς (archos), chief, and πέλαγος (pelagos), a sea, and others of Αἴγαιος (aigaios) and πέλαγος, the Ægæan Sea.

The Western or lesser continent consists of North and South America.

The great or eastern continent, having been known to the ancients, is often called the *Old Continent* or the *Old World.*

The western, having been unknown until its discovery by Columbus in the fifteenth century, is often called the *New World.*

8. **Peninsulas** are tracts, nearly, but not altogether, surrounded by water. The name is composed of two Latin words, *pene*, almost, and *insula*, an island.

9. **Isthmuses** are narrow necks, by which two comparatively large tracts are connected together. Isthmus is a Greek word, having the same signification.

The most remarkable examples of an isthmus are presented by the narrow tracts by which Africa is connected with Asia, and South with North America. The former being called the *Isthmus of Suez*, and the latter the *Isthmus of Panama.* Two towns, bearing these names, are built, one upon the former isthmus, on the coast of the Red Sea, and the other upon the latter, on the coast of the Pacific Ocean.

Peninsulas are often thus connected by an isthmus with the mainlands, to which they belong, but not always so. The name peninsula is given to tracts of land which, though partially surrounded by water, are nevertheless connected with the mainland by tracts much too broad to be entitled to the name of isthmus. Examples of this class of peninsular form are numerous, and among them may be mentioned the part of Southern Europe, which includes Spain and Portugal, called the *Spanish Peninsula* (Map 5.); the part of Italy, south of Lombardy and Piedmont, called the *Italian Peninsula* : the southern part of Greece, called the *Hellenic Peninsula* (Map 6); India, and numerous other similar masses of land, projecting in a pointed form into the sea (Map 7).

10. **Promontory** is a name given to a tract of land, of greater or less elevation above the level of the sea, which juts out from a comparatively large extent of land, and which therefore is peninsular in its form. The term, however, is usually applied to tracts of less extent than those which are denominated peninsulas.

11. **Capes and Headlands** are promontories having considerable elevation, so as to be visible from a great distance at sea.

12. **The Relief of the Land** has received different denominations according to its varying elevation above the general level.

13. **Plains and Lowlands** are parts of the land not much raised above the level of the sea, having considerable extent.

Various names are given to such tracts according to the language of the country and their condition in respect to vegetation. Thus an extensive sandy plain, destitute of all vegetation, is called a *Desert;* an example of such a plain on an immense scale is presented by the *Desert of Sahara*, in the North of Africa. Such plains are called *Landes* in France, *Steppes* in Russia, and *Llanos*, *Pampas*, *Selvas*, *Savannahs*, and *Prairies*, according as they are more or less covered with vegetation, in North and South America.

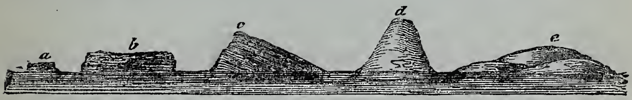


Fig. 1.—Forms of Plateaux, Hills and Mountains.

14. **Plateaux and Tablelands** are extensive level tracts, placed at considerable elevations above the level of the sea, or the general level of the surrounding country, *a b*, fig. 1.

15. **Hills** are elevations not exceeding about 1000 feet in height above the plain at their base, and having an outline variously formed; rounded, *e*, fig. 1.; ridged, *d*, fig. 1, or peaked, as *c*, fig. 1, and fig. 3.

Fig. 2.—Groups of Mountains.

16. **Mountains** are elevations generally exceeding 1000 feet in height, and likewise subject to a similar variety of forms, as shown in fig. 2.

The application of these terms "hills" and "mountains" is very arbitrary, elevations which receive the name of mountains in one place being lower than those called hills in another.

The forms of mountains are very various, and have an important relation to their external structure. Geologists are often able to determine the character of the rocks of which they consist by their outline. Thus, when the outline is characterised by needles rising to considerable elevations, as in fig. 4, the mountainous mass consists of the rocks called Gneiss. Such peaks, which are frequent upon the chain of the Alps, are called *needles*, *teeth*, and *horns*. Mountains are sometimes columnar in their structure, as in fig. 5, resembling fortifications seen from a distance. In this case they are usually formed of calcareous, that is, limestone rocks. Mountains composed of the same rocks also

Fig. 3. Fig 4. Fig. 5. Fig. 6.

Various forms of Mountains.

frequently assume the form shown in fig. 6, as if they were cut into steps forming a series of horizontal stages one above the other.

Mountains which assume the peaked or conical form, with a cavity or cup-like depression at their summits, are always of volcanic origin.

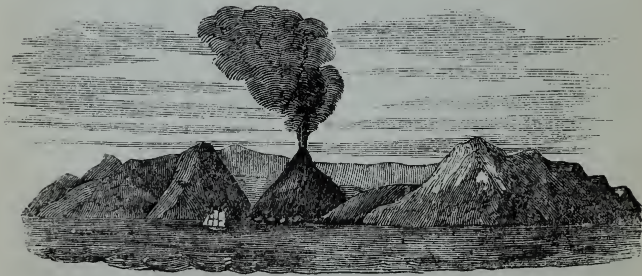


Fig. 7.—Barren Island in Bay of Bengal.

In fig. 7, an example of this is presented in the case of Barren island in the Bay of Bengal, consisting of a volcanic cone, 1848 feet high, which is frequently in a state of eruption, surrounded by other peaks of similar formation.

17. **Systems or Chains of Mountains** consist of series of mountains, of varying elevation and form, which are often continued over the whole extent of a continent.

18. **Oceans.**—The configuration of the sea, determined by the form of the lines in which it unites with the land, necessarily corresponds with the configuration of the land, and such forms are expressed by a system of geographical terms of correlative signification.

What a continent is to the land an *ocean* is to the water. This term, therefore, signifies a vast tract of water, unbroken, for the most part, by any tract of land.

Owing to the peculiar distribution of land and water on the globe, it follows that, strictly speaking, there is but one great ocean, between all points of which there is a continuous water communication. Nevertheless, geographers have found it convenient to divide this vast collection of water nominally into several distinct oceans, as will be explained hereafter.

19. **Seas.**—The term sea is applied to tracts of water one degree inferior in magnitude to the oceans, which are generally limited and enclosed between continents or large islands.

20. **Gulfs** are large inlets of the sea partially enclosed by land.

21. **Bays** are nearly the same as gulfs, but generally smaller. Like other geographical terms, these however are arbitrary and indefinite, some inlets called bays being greater than others called gulfs.

Gulfs and bays are the analogues of peninsulas and promontories.

22. **Straits** are narrow necks of water connecting tracts of greater extent. A strait is, therefore, the analogue of an isthmus.

A strait is often but improperly called by the plural term straits; thus the Strait of Gibraltar is frequently denominated the Straits of Gibraltar.

23. **Channels** are narrow tracts of water flowing between opposite coasts that are nearly parallel, and are much wider than straits.

24. **Roads and Roadsteads** are tracts of water sheltered by adjacent lands from violent or dangerous winds, having sufficient depth for safety, and not too great depth for anchorage. They are stations where vessels are accustomed to lie at anchor.

25. **Banks and Sandbanks** are parts of the bottom which lie so near the surface as to be attended with danger, and in places much affected by tides are often uncovered at low water.

26. **Reefs** are sunken rocks, which rise so near the surface, that the waves in passing over them are broken into foam, which thus render their presence manifest to mariners. In a calm sea, however, as there is nothing to indicate their presence, they are a great source of danger to the navigator.

27. **Soundings.**—The depth of the sea is found by a sounding-line, which is a cord of sufficient length, to the extremity of which a heavy piece of lead is attached. Upon this cord knots are made at intervals of five fathoms, the number of knots counting from the lead being indicated by visible marks. The lead is let down into the sea from the deck of the ship; the sounding-line to which it is attached being coiled round a cylinder, or reel, which turns freely on an axle. Two seamen hold up the reel by handles at the extremity of the axle, while another observes the line passing over the bulwark of the vessel. The

leaden weight sinking in the water draws with it the line, which thus unrolls itself from the reel, and this continues until the lead strikes the bottom. When that takes place the reel ceases to revolve and the line to sink, and the seaman who observes the sounding, notes the number of the knot which is nearest the surface, and thus obtains the depth, which is always expressed in fathoms.

The lead, suspended from the extremity of the sounding-line, is cup-shaped at its lower end, and grease, technically named *the arming*, is put into the cavity, so as to be capable of taking up by adhesion a portion of the shells, sand, or other substance, which is at the bottom, with which it comes into contact. This being drawn up, the navigator is informed not only of the depth, but of the quality and character of the bottom, which often serves him as a guide to his position.

In this manner surveys are made of the bottoms of all seas which are much navigated, and charts are drawn and engraved, upon each part of which is marked the number of fathoms of depth in the corresponding parts of the sea, and frequently the character of the bottom.

It happens fortunately that the general depth of the oceans and open seas is so considerable as to be attended with no danger to navigation. Such charts, therefore, as are here described are only necessary for navigation in enclosed seas and tracts of water near to coasts.

28. **Lakes** are sheets of water, of greater or less magnitude, completely surrounded by land, and having no superficial communication with the sea. They are, therefore, to the water what an island is to the land, and, like an island, the name is generally restricted to magnitudes which are not very great. A lake of great magnitude is generally called an inland sea.

Like other geographical terms, these, however, are arbitrary; some sheets of inland water called seas being less than others called lakes.

29. **Rivers** are large streams of fresh-water, formed by the rain which falls on elevated parts of the land, descending the declivities in streams, which, gradually uniting one with another, form at length a large course of water, which receives the name of a river.

30. **The Bed of a River** is a groove formed in the land, descending in a direction varying with the level of the surface, until it reaches the coast, where its water is discharged into the sea.

31. **The Banks of a River** are the land which confines its course on either side, and are distinguished as the right and left

banks, that which is to the right in descending the river, being called the right bank, and the other the left bank.

32. **Tributaries**, or affluents, are the streams which flow into a river on one side or other of its course. In the larger rivers these tributaries themselves are often considerable rivers, and receive along their course subordinate tributaries.

By reason of the common tendency of water to find the lowest level, rivers flow along the bottoms of valleys, and their winding courses, often very complicated, are determined by the varying direction of these valleys. Their tributaries run along the bottoms of smaller valleys, intersecting that of the principal river at various angles.

33. **The Valley**, along the bottom of which a great river flows, usually receives its name from that of the river, and is often of vast extent; the declivities which form its sides sometimes measuring hundreds, or even thousands, of miles.

34. **Watershed** is the name given to the declivities which thus determine the tributaries of a great river, and the whole extent of the valley is sometimes called the *basin* or hydrographic region of the river.

35. **Delta.**—A great river, in approaching its mouth, often diverges into different channels, forming angles with each other, and thus discharges itself into the sea by two or more mouths. These diverging branches are called a *delta*, from a fancied resemblance, presented by the two extreme branches and the line joining the two extreme mouths, to the Greek letter Δ, delta.

36. **Estuaries.**—The mouths of rivers are often placed in inlets of the sea, where the tide ebbs and flows, so that the waters of the sea alternately enter the mouth of the river and retire from it with the rise and fall of the tide, mixing with the water of the river, and thereby producing a constant state of agitation in the water of such an inlet. The name estuary has accordingly been given to such sheets of water, from the Latin word *æstus*, signifying the agitation of water such as that here described.

37. **Firths.**—The name firth, also written frith, is sometimes given to estuaries; this term, however, is more particularly applied in Scotland. Thus the estuary of the river Forth, which lies between Fifeshire and Edinburgh, is called the Firth of Forth.

The term firth or frith is generally assumed to be taken from the Latin word *fretum*, a strait or narrow neck of the sea. Mr. A. K. Johnson, however, considers it to be derived from the Scandinavian term *fiord*, pronounced *fiurth*, which has the same signification.

The principal terms composing the geographical nomenclature, and expressing the forms affected by the outlines of land and waters, and the forms of relief produced by the varying elevation and depression of the surface of the land, being clearly understood, a general description of the globe we inhabit, as it is diversified by land and water, and by the undulating surface of the former, will be easily rendered intelligible.

II.—ARABIA AND PERSIA.

THE GREAT EASTERN CONTINENT.

38. **Its extent and limits.**—This vast tract has an oblong form, as already indicated; its extreme length being somewhat more than twice its extreme breadth. It is included between 20° west and 190° east longitude, and between 35° south and 75° north latitude. Nearly its whole extent lies therefore in the northern part of the eastern hemisphere. A small portion of the north-western part of Africa, including Morocco, juts into the western hemisphere, and the southern promontory of the same division of the great continent, terminating in the Cape of Good Hope, projects into the southern hemisphere.

This continuous tract of land consists, as is well known, of three unequal divisions, which, though not detached one from another by sea, have received the name of continents. The smallest of these in magnitude, but transcendently the most important in its social and political character, is EUROPE, which occupies the northwest corner of the great continent, being separated from Africa by the Mediterranean Sea, and from Asia by a low chain of mountains called the Ural, a river of the same name, the Caspian Sea, a great sheet of inland water, into which this river discharges itself, and the Black Sea.

39. **Its divisions.**—If the whole superficial extent of the great continent be supposed to consist of eight equal parts, the area of Europe will be one of these parts, that of Africa three, and that of Asia, which covers the remainder, four.

Africa is divided from Europe by the Mediterranean Sea, and from Asia by the oblong tract of water, directed N.N.W. and S.S.E., called the Red Sea. This sea is connected with the Indian Ocean, lying to the east of Africa, and the south of Asia, by a narrow neck of water, called the Strait of Bab-el-Mandeb.

40. **The Mediterranean** sea, which forms one of the most important features in the western part of the great continent, lies in a direction nearly east and west, and communicates with the Atlantic Ocean by a narrow neck of water, interposed between the southern point of the Spanish peninsula, and the north-western corner of Africa, called the Strait of Gibraltar, from the rock of that name at the point of Spain.

41. **Relief.**—The relief of the surface of the great continent is characterised by an elevated ridge, the general direction of which is parallel to its longitudinal axis, and is consequently E.N.E. and W.S.W. very nearly, but the summit of this ridge is much nearer to the southern than to the northern coast of the continent, so that it divides its area very unequally. The declivity, therefore, which slopes to the southern coast, is much more rapid and shorter than that which extends to the northern coast.

42. **Its northern belt.**—The northern division consists of a great belt of flat surface, beginning with the plains of Holland at the west, and terminating with the deserts of Siberia at the east, being only interrupted by the chain of Ural Mountains, running north and south at the confines of Europe and Asia. Except where human industry has redeemed it, and brought it under cultivation near its western extremity, the characteristic of this plain is that of marshiness and insalubrity.

43. **The southern belt.**—The more limited plain south of the ridge-summit, already mentioned, commences at the west with the great African desert of Sahara, and stretches with little interruption across Arabia, Persia, and Northern India, to the shores of Kamtschatka.

44. **Prevailing mountain-chains.**—The various mountain-

chains, the combination of which forms the main ridge of the great continent, commence with Mount Atlas and the Pyrennees at the extreme west, and are continued by the Alps and the Himalaya to the Altaic mountains at the extreme east.

45. **Outlines of Europe; their adaptation to Commerce.**—The most striking geographical feature by which Europe is distinguished from the other parts of the great continent, consists in the numerous and extensive inlets of water by which it is penetrated and intersected in all directions. No equal extent of land in any part of the globe presents a like phenomenon, and to this, as much as to its temperate climate, must undoubtedly be ascribed the immense social, commercial, and political predominance which it has acquired and maintained. By this reticulation of inland seas, gulfs, bays, and straits, navigation and commerce arrive within short distances of all its internal centres, and its vast extent of coasts is studded with cities and towns, and sheltered ports and harbours, which become so many emporiums of commerce, and centres and sources of wealth and civilisation.

46. **White Sea.**—At its extreme north, Europe is penetrated by an enclosed sheet of water of great magnitude, called the White Sea. On the west, the Baltic enters it, ramifying in different directions, throwing out north and west the gulfs of Bothnia and Finland, and sprinkled with islands and vast peninsulas, which form kingdoms of great importance, such as Denmark.

47. **Norway and Sweden** are formed into a great peninsula, separated from the continent by a broad neck of land, included between the North Sea on the west, and the head of the Gulf of Bothnia on the east.

48. **British Isles.**—Nearly opposite the mouth of the Baltic, and the north-western point of France, are placed the British Isles, separated from the coast of Holland and Belgium by the German Ocean, and from that of France by the English Channel and the Strait of Dover. These islands, combined with the subordinate ones with which they are surrounded and skirted, such as the Shetlands, the Orkneys, the Western Isles, the Isles of Man and Anglesea, the Scilly, and the Channel Islands, may be considered as forming an archipelago, the principal divisions of which are richly intersected by channels, bays, and gulfs, which have so favoured navigation, as to enable the British nation to attain and maintain that commercial and naval pre-eminence, for which she has so long been celebrated.

49. **France**, the most important and powerful of the European states, occupies the centre of Western Europe. Her territory is separated on the east from those of the German states by the Rhine,

from that of Switzerland by the chain of the Jura, from Italy by the Alps, from Africa by the Mediterranean, and from Spain by the Pyrenees. On the west it is limited by the Atlantic, and on the north, in the absence of any natural boundary, is divided from Belgium by a frontier settled by political conventions.

50. **Spain and Portugal** occupy a portion of land having the peninsular form, the neck by which it is connected with the continent extending from the Bay of Biscay to the Gulf of Lyons, and being traversed by the chain of the Pyrenees. This neck of land, so much narrower than the general width of the Spanish peninsula, is nevertheless much too wide to entitle it to the name of an isthmus.

In the geography of Europe the tract thus occupied by Spain and Portugal is usually called the **Peninsula**, without other designation.

51. **Italy.**—The southern part of Italy projects into the Mediterranean Sea in the form of an oblong tract of land, having at its southern extremity a smaller tract nearly at right angles to it; the outline of the whole presenting a striking resemblance to a boot. The Italian territory, however, occupies a wide extent of land north of the boot, enclosed on the north by the chain of the Alps. This northern part of Italy includes the territories of Venice and the Milanese, called Lombardy, at present part of the Austrian empire, and the kingdom of Sardinia. That part of the Italian territory forming the boot, being nearly surrounded by water, with the Adriatic on one side and the Mediterranean on the other, is distinguished as the Italian Peninsula.

52. **Sicily.**—Immediately at the toe of the boot, and separated from it by a narrow neck of water, celebrated in history as the Strait of Messina, is the fertile and beautiful island of Sicily, one of the most remarkable features of which is the volcano called Mount Etna.

53. **Greece** projects into the eastern end of the Mediterranean, having, like Italy and Spain, the peninsular character. These three tracts have been noticed even by ancient geographers as the Spanish, Italian, and Hellenic peninsulas.

54. **Archipelago.**—The arm of the Mediterranean which, turning to the north, intervenes between the Hellenic peninsula and the coast of Asia Minor, thickly sprinkled with islands, is the Archipelago or ancient Ægæan Sea, from which all other tracts of water of a similar character have taken their name.

55. **Dardanelles and Bosphorus.**—The Archipelago is connected with the great inland sea, called the Black Sea or the Euxine, by a narrow neck of water, consisting of two straits, between which lies a wider strip of sea. The strait which is next

the Archipelago is called the Dardanelles, the ancient Hellespont; and that which is next the Black Sea, the Bosphorus; the intermediate water being called the Sea of Marmora.

56. **The Black Sea** is nearly enclosed by land, but communicating through the Bosphorus with the Archipelago and the Mediterranean, it cannot properly be considered as a lake. Its water is, nevertheless, much less salt than that of the ocean, and it is consequently more readily frozen. Its depth near the shore varies from 24 to 220 feet, and in the middle is more than 1000 feet.

57. **Sea of Azof.**—This sea communicates with a smaller one north of it, called the Sea of Azof, by a narrow neck of water, called the Strait of Yenekali. A tract of land nearly surrounded by the waters of the Black Sea and the Sea of Azof, and connected with the continent by a narrow neck of land, is called the Crimea; the connecting neck being called the Isthmus of Perikop. This peninsula has been celebrated for the fortress of Sebastopol erected by Russia near its southern extremity, and destroyed in 1855 by the allied armies of France and England.

58. **The Caspian.**—Near the southern confines of Europe and Asia is the largest lake in the world, called the Caspian Sea. Its water is salt, but much less so than the ocean, and it is shallow, even at its centre, the depth not exceeding 300 feet. That it can have no immediate and uninterrupted subterranean communication with the Black Sea, which is near it, is proved by the fact that the level of its surface is 82 feet below that of the latter sea.

59. **Africa** is an immense triangular-shaped tract of land, the base of which is presented towards the north, and the point to the south. Its coast is everywhere nearly uniform, and entirely destitute of those indentations for which Europe is so remarkable. It projects southwards into the great ocean, which it divides into two regions, of which the western is called the Atlantic, and the eastern the Indian Ocean. As has been already stated, Africa is separated from Asia by the Red Sea, except at the point where they are connected by the narrow isthmus of Suez.

This division of the great continent is, beyond all comparison, the most uncivilised and desert portion of the globe. It includes a vast range of country, extending from the northern to the southern tropic, and lying, therefore, altogether in the torrid zone. By reason of the great extent of desert of which it consists, the insalubrity of its climate, and the barbarous character of its inhabitants, it is little known to Europeans.

60. **Its Climatological Zones.**—It may be considered as consisting of a succession of zones, separated by parallels of latitude, having different physical characters.

61. **The Tell and Sahara.**—The northern zone, included between the ridge of Mount Atlas and the Mediterranean, is a band of fertile country, generally called the *Tell*, probably from the Latin word *tellus*, the earth. South of this is a vast band, running east and west, about 1800 miles broad, comprising Sahara or the great desert. This extensive surface consists of tracts of sandy and stony soil, rarely producing vegetation, and, when it does, of the most scanty description, with the exception of certain spots appearing here and there in this ocean of desolation, like islands of fertility. These are called Oases, and depend for their productiveness on local springs.

62. **Valley of the Nile.**—On the west this desert not only descends to the verge of the ocean, but is continued with the same character for many miles beneath its surface and beyond the coast. On the east, it descends by a series of sterile terraces to the valley of the Nile, where the soil suddenly acquires a high degree of fertility, which character it retains throughout the whole extent of country between the Nile and the Red Sea. The entire valley of the Nile, from the skirt of the Desert to the Delta, and from the right bank of the river to the Red Sea, has been celebrated in ancient history for its general fertility, a character, nevertheless, which is not altogether without exception, an example of which is presented in the tract over which the route between Cairo and Suez is conducted.

63. **The central Belt** of Africa, immediately south of the great desert, has quite a different character, being both fertile and populous.

64. **The fourth zone,** lying south of this, is almost unknown, except on its seaboard. It is supposed to consist of an extensive and elevated table-land, with lofty mountain-ranges rising out of it, from which character it is distinguished in geography as High Africa.

65. **The southern zone** of the great African peninsula consists of a triangular area, the vertex of which projects into the Southern Ocean, and is terminated by the celebrated Cape of Good Hope. This part is diversified by hill and valley, and is naturally fertile, supplying extensive pasturages. The native tribes which inhabit it are the Hottentots and Caffres. The English colony, originally Dutch, has been generally confined to the southernmost part of the angle, but has a constant tendency to push their territory further north, thereby coming into contact, and frequently into conflict, with the natives.

66. **The coasts.**—It has been already observed that the coasts of Africa are singularly destitute of all projections and indentations, and, consequently, ill-adapted for commerce. For the

same reason, there is a remarkable absence of those numerous islands which enrich all coasts deeply indented, which considered in their physical character are in fact parts of the mainland, separated from it by valleys so deep as to allow the sea to flow through them. Madagascar, on the east coast, is the only African island. There are a few islands of much less magnitude, called the Comano Islands, between Madagascar and the coast. Most of the other islands which appear in the Indian Ocean are too distant to be regarded as mere appendages of Africa.

III.—AUSTRALASIA.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER II.

67. Asia.—68. Its Plateaux.—69. The eastern Plateau.—70. Its physical character.—71. The western tableland.—72. British India : Dekkan plateau.—73. Australia.—74. Australasia. — 75. Polynesia.—76. British Colony : its territory and physical features.—77. Its climate. —78. Vegetable productions.—79. The indigenous animals.—80. Minerals: Gold.—81. Aboriginal tribes. The Western, or New Continent. — 82. Its extent and form. — 83. Divisions : South America. — 84. Central America. — 85. North America. —86. Its extent and limits. — 87. Its political divisions. — 88. Gulf of Mexico and Caribbean Sea.—89. Relation between the coasts of the old and new continents.—90. The relief.—91. Chippewayan

and Rocky Mountains.—92. Cordilleras and Andes.—93. Andes of Patagonia and Chili.—94. Andes of Bolivia and Peru.—95. Cordilleras.—96. Potosi.—97. Pampas of Patagonia and Buenos Ayres.—98. Selvas of the Amazon.—99. Llanos of Orinoco.—100. Alleghanies.—101. Eastern plain of North America.—102. Great valley of the Mississippi.—103. The Prairies.—OUTLINES OF THE LAND.—104. The prevalence of the peninsular form.—105. The South American peninsula.—106. The North American peninsula.—107. The West Indian archipelago.—108. The peninsula of Florida.—109. Lower California.—110. Greenland.—111. Africa.—112. Australia.—113. New Zealand.—114. Similar tendency in smaller regions.—115. The Spanish peninsula.—116. The Italian peninsula.—117. The Hellenic peninsula.—118. The Crimea.—119. The Scandinavian peninsula.—120. European peninsula.—121. The Indian peninsula.—122. Further India.—123. Hemisphere of most land.—RIVERS.—124. Formation of rivers.—125. Effect of a single ridge.—126. Example in the eastern continent.—127. Example in South America.—128. Effect of parallel ridges.—129. Chief tributaries considerable rivers.—130. Example of Missouri.—131. Trifling elevation of watershed.—132. Portage.—133. Examples of rivers in North America.—134. Eastern rivers.—135. Western rivers.—136. The Mississippi and its tributaries.—137. Valley of the Mississippi.—138. Red River, Arkansas, Ohio.—139. St. Louis.—140. Illinois.

67. **Asia,** constituting in geographical extent fully half the great continent, and occupied by a population numbering half the total amount of the human race, is in many respects an interesting quarter of the globe. It is in immediate geographical continuity with Europe, separated from Egypt only by the narrow strip of water called the Red Sea, and connected with it by the isthmus of Suez, and separated on the east from the American continent by the narrow neck of water called Behring Straits. Its eastern coast is fringed with innumerable islands, and indented by large bays and gulfs; and its southern points are in a certain sense connected with the new continent of Australia by the archipelago which intervenes between the Indian and Pacific Oceans, of which the most considerable islands are Sumatra, Borneo, Pappua, and Java. The equator traverses the middle of this archipelago, the whole extent of which is included between 20° of north and 10° of south latitude.

68. **Its plateaux.**—The mainland of Asia consists of two extensive plateaux, each of which is limited and intersected by mountain-chains, from which the surface falls by a succession of slopes and terraces to the level of the lowlands.

69. **The eastern plateau,** which is the most elevated, including Thibet and the desert of Gobi or Shamo, has an elevation varying from 4000 to 15000 feet above the level of the sea.

This great tableland has for its southern limit the Himalaya chain, for its northern the Altai, and the chain called Thian. On the west it is limited by the Bollortagh, and on the east by a chain running directly north from Pekin called the Khingan mountains.

70. **Its physical character.**—The physical character of this vast plateau may be in some degree comprehended, when it is stated that it consists of three-fourths of a million of square miles of surface, having a general elevation greater than that of the most lofty mountain-ranges of Europe.

This plateau descends towards the north by gentle slopes, so as to convert the extensive zone of surface along the northern coast into a vast plain, the general elevation of which above the surface of the sea does not exceed a few hundred feet.

On the south and south-east sides, the great plateau advancing comparatively close to the coast, the descent is much more rapid.

71. **The western tableland** embraces the tract between the Caspian Sea and the Persian Gulf on the north and south, and the river Indus on the east. It does not exceed 4000 feet in elevation, and is generally less. This tract, called the tableland of Iran, the ancient Persia, is now divided into Cabul on the east, and Persia on the west. Stretching in the direction of the north-west to Asia Minor, it slopes gradually down to the archipelago.

72. **British India: Dekkan plateau.**—One of the geographical features of this division of the great continent is the triangular projection which juts down into the Indian Ocean, and constitutes the chief part of the territory of British India. This also consists of a plateau, of moderate elevation, called the *tableland of Dekkan*. Between this, which covers the whole extent of the peninsula and the Himalaya mountains which run east and west, is a plain of low elevation, called the plain of Hindoostan, forming the valley along which the Ganges, with its tributaries, flows from west to east, forming its delta, and discharging itself into the Bay of Bengal, at the northern extremity of that gulf near Calcutta. The western portion of the same plain slopes towards the Arabian Sea, and is the valley similarly drained by the Indus and its tributaries.

73. **Australia,** formerly called New Holland, is an insular mass, whose extent and importance are such that it has ceased to be called an island, and is now generally ranked as a continent. It is placed south of the line between latitudes 15° and 40°. Near it are several other islands of less magnitude, the principal of which is New Zealand. South of it is a smaller island, formerly called Van Diemen's Land, and now denominated Tasmania.

74. **Australasia.**—The group consisting of Australia, Tasmania, New Zealand, and the smaller islands near them, are

called by modern geographers Australasia, being the most considerable tracts of land in the southern latitudes. The various islands sprinkled in countless numbers over the Pacific Ocean, comprising Australasia itself, have received the general name of Oceania.

75. **Polynesia.**—Those which lie between the Indian Archipelago and the western coast of America, taken collectively, have been called *Polynesia.*

76. **British Colony; its territory and physical features.**—From the circumstance of the recent gold discoveries, and the consequent emigration from the United Kingdom to Australia, this colony has acquired a greater interest than any which its mere geographical pretensions could claim for it. It may therefore be desirable here to notice its physical character and conditions.

Notwithstanding the immense immigration which has taken place, and the excitement attending the mineral researches, of which it has become the theatre, the surface of this great island has been but very imperfectly explored. One of the most remarkable and geographical characters it presents is the complete absence of large navigable rivers, and the uniform outline of its coast, which has no indentations forming bays, gulfs, or other inlets. It is surrounded by a chain of mountains, the summit-ridge of which is from 30 to 40 miles from the shore. The chain running along the eastern coast, which is best known, is called the Australian Alps at the extreme south, the Blue Mountains near Sidney, and the Liverpool chain towards the north. From the slopes of these mountains a few small rivers descend, which are so inconsiderable as to be nearly dry in summer. The interior consists of a series of low plains, which include good pasturages, and large tracts covered with sand and shells, which have an appearance such as would be presented by a surface from which the sea had recently retired. Some considerable streams have been seen in the interior, but whether they flow into an inland sea like those which run into the great Asiatic lake, or are absorbed by the sands, has not been ascertained.

One of the most curious physical characters connected with this island is the existence on its north-eastern coast, at a distance of from 20 to 70 miles, of the longest coral reef in the world, measuring about 1200 miles in length, and rising out of the bosom of a sea said to be fathomless. The breadth of this reef varies from a few hundred yards to several miles.

77. **Its climate.**—When it is remembered that the extreme latitudes of Australia are 15° and 40°, it may be expected that its climate must be mild and salubrious. With a drier atmosphere it has all the thermometric characters of Southern Italy. The

vegetation seems to be maintained by the deposition of dew, for it often happens that intervals of several years elapse without rain. When rain does occur, however, it is periodic, and prevails through three months.

78. **Vegetable productions.**—The natural vegetable productions are neither considerable nor useful; there is no species of edible fruit. The trees composing the woods appear to be of one uniform family, the foliage being scanty and almost shadowless. On the other hand, transplanted vegetation is easily naturalised. Districts are found adapted to the cultivation of all sorts of grain; but, for the present, the most advantageous employment of the soil is for pasturage.

79. **The indigenous animals** are few, being mostly of the family of marsupia, such as the opossum and kangaroo. The most remarkable and anomalous of these animals is one called the ornithorhynchus, which is a sort of connecting link between birds and quadrupeds, having the bill and feet of a duck, and the body and fur of a mole.

80. **Minerals—Gold**—It is well known that gold in large quantities is found in this region. It may be added, however, that coal and iron also exist there in inexhaustible quantities, as well as marble, lead, and copper.

81. **Aboriginal Tribes.**—The native tribes, which appear to prevail in but limited numbers, are in the lowest state to which nature can sink. They are generally nomadic, but sometimes build rude villages, and subsist by fishing on the coast.

So utterly degraded is their condition, moral and physical, that many tribes are unprovided with clothing, practise cannibalism, and are wholly destitute of social and religious ideas.

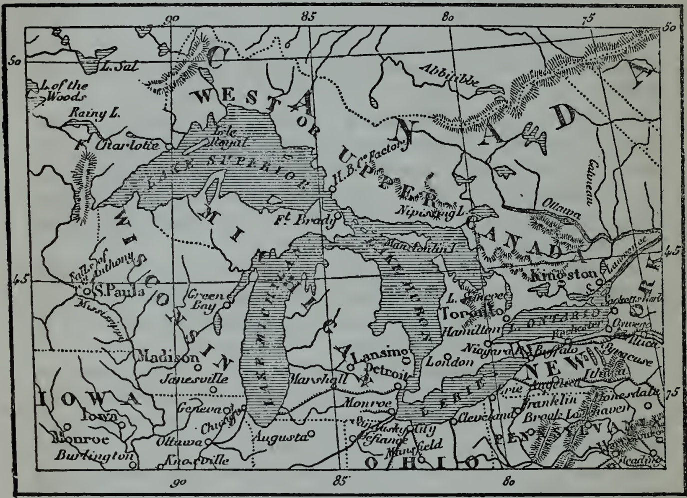
THE WESTERN, OR NEW CONTINENT.

82. **Its extent and form.**—Like the great eastern continent, the western is an oblong tract of land, the length of which intersects the parallels of latitude obliquely, being directed first from the S. S. E. to N. N. W. and then turning eastward in approaching the pole. It extends from 50° S. lat. to the utmost limit of polar discovery.

83. **Divisions—South America.**—This continent consists of two peninsulas, connected by a narrow tract of considerable length. The southern peninsula resembles Africa in its general outline, having a triangular form, with its base towards the north, and its vertex to the south. It also resembles the African continent in having coasts but little indented by bays or gulfs,

but differs from it in being intersected by large and extensive rivers.

84. **Central America** is the tract of land uniting South America with the northern peninsula. Its southern part being not more than 30 miles wide, is denominated the isthmus of Darien or Panama, a town of the latter name being on its western coast.



IV.—UNITED STATES—CANADA.

85. **North America,** like Europe, is indented with numerous bays, and its northern division has the largest collections of fresh water in the world, consisting of five extensive lakes,—called Superior, Michigan, Huron, Erie, and Ontario, which communicate with each other, and discharge their water through the River St. Lawrence into the gulf of that name.

86. **Its extent and limits.**—North America is separated from Asia by Behring Strait on the west, and from the large island of Greenland by Baffin's Bay and Davis's Strait on the north and east.

A sort of northern archipelago intervenes between this continent and Greenland, into which numerous promontories project, and the waters of which are variously denominated, the largest of these inlets being Hudson's Bay.

87. **Its political divisions.**—In political geography North

America consists of several divisions, the central part being the United States, the north-eastern British America, the north-western angle near Behring Strait, Russian America, and the part forming the southern point, Mexico.

88. **Gulf of Mexico and Caribbean Sea.**—The large inlet of the ocean enclosed between the northern coast of South America, the southern coast of North America, and the eastern coast of Mexico and Central America, consists of the Gulf of Mexico and the Caribbean Sea, its eastern part, sprinkled with the West Indian islands, forming an archipelago.

89. **Relation between the coasts of Old and New Continent.**—It has been observed by Humboldt, that on comparing the eastern coast of South America with the western coast of Africa, the same correspondence is observed between them as is usually seen in the opposite sides of a valley or ravine; from which he argues that the bottom of the Atlantic, which flows between these continents, ought to be regarded as an extensive valley, the sides of which, rising to an elevation above the level of the water which fills it, form the coasts of the two continents. Thus the concavity on the African coast, called the Gulf of Guinea, has a corresponding convexity on the South American coast forming the territory of Brazil, and the convexity at the north-western corner of Africa, of which the coast of Morocco forms a part, corresponds with the opposite concavity formed by the Caribbean Sea and the Gulf of Mexico. So that if the two continents were moved towards each other, and brought into contact, their coasts would fit into each other, like the dove-tailed edges of carpentry. The Atlantic, following the course of this submarine valley, entering between the Cape of Good Hope and Cape Horn, flows first in a northerly direction, a little towards the east, next, after passing the Gulf of Guinea, in a north-westerly direction, and finally, after passing the north-western coast of America, in a north-easterly direction.

90. **The relief** of the western continent is characterised by a continuous ridge of considerable elevation, which traverses it longitudinally from its northern to its southern limit, lying much nearer to the western than to the eastern coast.

91. **Chippewayan and Rocky Mountains.**—The part of this ridge or mountain-chain which traverses North America, commencing at the Frozen Ocean, is called in its northern division the Chippewayan range, and in its southern division by the better known name of the Rocky Mountains.

92. **Cordilleras and Andes.**—After passing along Central America, this ridge takes the name of the Cordilleras and Andes, and rising to much greater heights, and throwing up vast peaks

which are frequently volcanic, it is continued in a direction parallel to the western coast of the continent, until it terminates in the Tierra del Fuego, the southern point of which is called Cape Horn.

93. **Andes of Patagonia and Chili.**—Between this point and Chili, returning northwards, the slopes of the Andes descend to the waters of the Pacific, the coast being lined with numerous islands and indented with arms of the sea, an outline which indicates the continuation of the mountain range below the waters of the ocean; the capes, promontories, and islands being merely the ridges and summits of the spurs and peaks of the main range, whose bases are established at the bottom of the ocean. Proceeding northward, the general direction of the chain takes a more inland course, leaving between its base and the sea a long and flat tract of land, whose coast is no longer broken by the indentations just described, is completely destitute of islands, and forms no shelter for navigators.

94. **Andes of Bolivia and Peru.**—Still proceeding northward and approaching the Peruvian territory, the general elevation of the Andes rapidly increases, and their summits rise to vast elevations above the snow-line; among these is the Nevado Aconcagua, having an elevation of 24000 feet, and being the most lofty point of the western continent. This peak was originally volcanic, but within historic record it has not been active.

About latitude 24° south, the chain takes the name of the Peruvian Andes, and here it is at a considerable distance from the western coast, from which it is separated by a sandy desert.

95. **Cordilleras.**—North of 21° lat. south, the chain of the Andes diverges into two or three separate ridges, called Cordilleras, which are connected at different points by their common spurs issuing transversely to their directions, so as to form a net-work enclosing numerous valleys, the bottoms of which are elevated to a considerable height above the level of the sea, forming in many cases plateaux and tablelands of great extent, the most remarkable of which is that of Desaguadero, which measures 400 miles in length, with a breadth varying from 30 to 60, and a general elevation of nearly 13000 feet above the level of the sea. Vast peaks are thrown up from the borders of this immense plateau to the height of more than 8000 feet above the surface, rising far above the snow-line.

96. **Potosi.**—Upon this extensive tableland, whose area is three times that of Switzerland, stands Potosi, the highest city in the world, at an elevation of 13330 feet above the level of the sea, with a population of 30000. This city is built on the

northern declivity of a mountain called Cerro de Potosi, which is rich in mineral veins, and especially in silver.

97. **Pampas of Patagonia and Buenos Ayres.**—Since, as has been explained, this great chain runs close to the western coast, it may be expected that a vast tract of plains, or lower lands, must extend from the foot of its eastern declivity to the eastern coast of the continent. This tract in South America is covered with the deserts and pampas, as they are called, of Patagonia and Buenos Ayres, the surface of which is sandy and marshy, or saline, producing nothing but a scanty pasture and stunted trees.

98. **Selvas of Amazon.**—Another portion, consisting of the valley of the great River Amazon, called Selvas, consists of a space of more than two millions of square miles, a part of which is covered with natural forests, and the remainder with grassy pampas.

99. **Llanos of Orinoco.**—The valley of the Orinoco, another division, is characterised by vast flat lands, called Llanos, covered with long grass, interspersed here and there with palm trees, used by the traveller in these inhospitable regions as landmarks.

100. **Alleghanies.**—Extensive lowlands stretch in like manner over North America, between the chain of the Rocky Mountains and the eastern coast. This division of the continent is also intersected in a direction parallel to the Rocky Mountains, and nearer to the Atlantic by a chain of much lower hills called the Alleghanies, which, like the former, extend from the Gulf of Mexico to the Arctic Ocean, enclosing an area of more than 3,000000 of square miles.

101. **Eastern Plain of North America.**—Between the chain of the Alleghanies and the Atlantic coast is another plain parallel to the former, of nearly equal length from north to south, but of less width. The eastern coast is indented and fringed with numerous bays and creeks, which favour commerce and navigation.

102. **Great Valley of the Mississippi.**—The extensive valley lying between the chain of the Alleghanies and the Rocky Mountains is drained by the Mississippi, the largest and most important river in the world, next to the Amazons, which, nevertheless, it exceeds in length, though inferior to it in the extent and number of its tributaries.

103. **The Prairies.**—Among the features which characterise the land in the western continent, and more especially in its northern part, the Prairies demand especial notice. These are vast plains, generally covered by deep herbage, and which form a level so dead and uniform, that it is impossible to resist the

impression that they must have been once the bottoms of large sheets of water, since nothing but sedimentary deposition could produce a level so uniform. The extent of many of these plains is so great, that in traversing them points may be attained from which all the surrounding country will cease to be visible, so that the prairie presents to the observer a circular horizon, like that witnessed at sea from the deck of a ship.

As there are, in general, no roads or paths traversing these vast plains, the traveller who ventures across them can only guide his steps by a compass, or by the stars.

OUTLINES OF THE LAND.

104. The prevalence of the peninsular form with the pointing southwards is one of the most remarkable features in the configuration of the land. The angular point is also generally succeeded or surrounded by one, or several islands; and where such islands are not apparent, the tendency towards their formation is discoverable by the soundings, which prove the existence of shoals in the places where such islands would otherwise be apparent. A general view of the map of the world will strikingly illustrate these observations.

105. **The South American Peninsula** is an example of such a form upon a grand scale. Like all the other forms of this class, it is a triangle, having its base presented towards the north, and its vertex jutting into the Southern Ocean, where it terminates in the point called Cape Horn.

Its apex is broken by the ocean into a multitude of islands, the largest of which, separated from the main-land by the Straits of Magellan, is called the Tierra del Fuego, or land of fire, from several volcanic peaks which rise from it to the altitude of 4000 feet. The southernmost island of the Fuegian archipelago terminates in the headland, or promontory, so well known as Cape Horn.

106. **The North American Peninsula** has a like form, its southern point being Mexico; but instead of terminating in the ocean, it is united with the South American peninsula by a tract of land called Central America, which, taken as a whole, may be regarded as an isthmus, although geographers have, in this case, limited that name to its southernmost and narrowest part, called the Isthmus of Panamà.

107. **The West Indian Archipelago** stands in the same relation to the North American peninsula as the Fuegian archipelago to the southern peninsula. This group of islands, celebrated as being the theatre of the great discovery of Columbus, is included

in the tract of water enclosed between the northern coast of South, and the southern coast of North, America. When Columbus undertook his voyage, his purpose was to sail to India round the western hemisphere of the globe, and when he arrived at the island of St. Salvador, one of the Bahama group, he imagined that he was on the coast of India; and hence this, and the other islands of the archipelago subsequently discovered, came to be called the West Indies: they are, however, more commonly denominated by French and foreign geographers the Antilles.

The extensive tract of sea enclosed by the coasts of North and South America, and the chain of West Indian Islands, is denominated the Gulf of Mexico, and the Caribbean Sea; the former being included by the southern coast of North America, and the northern of Central America, and the latter by the northern coast of South America, the West Indian Islands, and the eastern coast of Central America.

108. **The Peninsula of Florida** presents another example of the like form. It is the southernmost point of North America, jutting into the ocean between the Atlantic and the Gulf of Mexico, and terminating in Cape Sable, directly north of the well-known harbour and city called Havannah, in the island of Cuba.

109. **Lower California** has the same peninsular form, directed southwards. It lies on the western coast of Mexico, from which it is separated by an inlet of the Pacific, called the Gulf of California. It is terminated at its southern point in a headland called Cape St. Lucas.

110. **Greenland**, in the extreme north, presents an example of similar formation, being formed into an acute angle, jutting out into the Atlantic towards the south.

111. **Africa**, in the Old World, is a stupendous example of the same peninsular outline. Like South America it is triangular, the base being presented to the north, and the vertex to the south. There are no islands below its vertex, but the tendency to the formation of one is indicated by the shoal called the Lagullas Bank, well known to mariners.

112. **Australia** has a similar form, terminating with the island now called Tasmania, and formerly known as Van Diemen's Land.

113. **New Zealand**, on a much smaller scale, presents a like example, terminating with an island called New Leinster.

114. It is very remarkable that this tendency to the peninsular form with a southern vertex, not only prevails in the continents, but is discoverable equally in the more minute outlines of the land which determines the shores of gulfs, bays, and inland seas.

115. **The Spanish Peninsula**, including Portugal, is an ex-

ample of the same prevailing form, its southern apex being marked by the celebrated rock of Gibraltar, separated from the northern coast of Africa by the narrow neck of water called the Strait of Gibraltar.

116. **The Italian Peninsula** juts southwards into the Mediterranean, with the islands of Sicily and Malta, and the small archipelago formed by the Lipari Islands, at its southernmost point.

117. **The Hellenic Peninsula** is a like example, terminated by the Morea, and surrounded near its southernmost point by the Ionian Islands.

118. **The Crimea,** in the Black Sea, is a peninsula of like form and position, terminating with a southern vertex near Sebastopol.

119. **The Scandinavian Peninsula** consists of Norway and Sweden, and enclosed between the Northern Atlantic on the west, and the Baltic and the Gulf of Bothnia on the east, presents, like the others, an apex to the south, and Zealand, and other smaller islands, lie off its southern point.

120. **European Peninsula.**—Humboldt observes that Europe itself may be regarded as a great peninsula projecting from Asia, and enclosed between the Mediterranean and Black Sea on one side, and the Baltic and Arctic Ocean on the other.

121. **The Indian Peninsula** juts into the ocean southwards, having, like the others, a triangular form, and the island Ceylon off its southern apex.

122. **Further India.**—The tract of land called Further India, lying to the south of China, and including Cochin China, Siam, and Burmah, is another example of like form, terminating in the Malayan promontory with Singapore at its apex, and the Indian archipelago around its point.

123. **Hemisphere of most Land.**—There is a certain hemisphere of the globe within which nearly the whole of the land is included, the middle point of which is at the south coast of England. If an observer were elevated directly above this point, so as to obtain a bird's-eye view of the earth, he would see the whole of Europe, Asia and Africa, North America, and the chief part of South America, all comprised within the visible hemisphere: the only parts of the land which would be included within the hemisphere beyond his view would be the southern point of South America, Australia, and the islands of the Indian Archipelago.

In Map 8, we have given these two hemispheres, having reproduced them from the Physical School Atlas of Alexander Keith Johnston, a work which we strongly recommend to students to aid them in comprehending this tract.

RIVERS.

124. **Formation of Rivers.**—The origin of all rivers is the evaporation of the ocean. The surface of the oceans and seas has an extent, as has been already explained, equal to nearly three-fourths of the whole surface of the globe. This extensive mass of water is subject to an incessant process of evaporation. In this process, the pure water is separated from the salt and other solid matter which it holds in solution. The vapour, therefore, which ascends into and mixes with the atmosphere, is that of pure fresh water. Being lighter bulk for bulk than the air, it rises into the higher regions, where it is transported in different directions by atmospheric currents. By the operation of temperature and electricity, it is converted into clouds, which, attracted towards the most elevated points of the land, collect in dense masses around the ridges and summits of the mountains, where, being condensed and reconverted into water, and sometimes congealed, it is precipitated in the form of rain or snow. From these heights it descends by the common principle of gravitation, either along the surface of the declivities, or through the fissures and interstices of the soil, finding its way to the lower levels; and, following these in their devious and winding course, it at length returns to the sea, with which it mingles, to be again evaporated and sent once more through the same series of physical changes.

125. **Effect of a single ridge.**—When a tract of country, bounded on either side by the sea, is traversed by an elevated ridge or chain of mountains, the rain and snow deposited upon them descends in streams along their slopes at either side, forming at first rivulets, which, coalescing, swell into larger streams, and acquire the character of rivers. These, following the declivities and winding through the valleys, find their way on the one side or the other to the sea. In this case, the general direction of the rivers will be at right angles to the ridge which traverses the country. The rapidity of their streams will be proportionate to the steepness of the declivity, and their length to the distances of the prevailing ridge from one or other coast.

126. **Example, in the Eastern Continent.**—An example of the play of this principle is presented in the great eastern continent, where, as has already been explained, the mountain-chains running from west to east are much nearer to the southern than to the northern coast. The rivers, therefore, which flow towards the south, are generally shorter and more rapid, while those which flow towards the north, passing over exten-

sive tablelands and plains having little declivity, are comparatively long and sluggish.

127. **Example in South America.**—South America presents a similar example. The chain of the Andes traversing the country north and south, and much nearer to the western than the eastern coast, gives a similar character to the rivers, those which flow to the west being short and rapid, and those which flow to the east being longer and slower.

In the northern part of South America, the principal mountain chain, diverging into several distinct ridges of the Cordilleras, produces a complicated system of ravines and valleys, which divert the course of the waters in various directions, so that many of the rivers flow northwards and north-westwards into the Caribbean Sea.

128. **Effect of Parallel ridges.**—When a tract of country is traversed by two ridges in nearly parallel directions, their declivities, which look towards each other, form a valley of greater or less width. The rain precipitated upon these slopes, collecting in streams, descends from either side to the lowest point of the valley where they coalesce, and settling into a bed or channel, flow along the lowest level of the valley, forming a river whose course is parallel to the general direction of the bounding ridges, and which continues its course until it discharges its waters into the sea.

In ascending a river, it is found, as may be expected, that the quantity of water which flows in it becomes less and less as the distance from its mouth increases. Since the total collection of water must be proportionate to the number and magnitude of the tributaries above the point of observation, the higher that point is, the less will the number of such tributaries be, and consequently the less the quantity of water in the main stream.

129. **Chief tributaries considerable rivers.**—In the case of all the great rivers, the principal tributaries themselves are rivers of considerable magnitude and importance, and some which have been classed as tributaries might with greater propriety have been considered as the main stream.

130. **Example of Missouri.**—Thus for example the Mississippi receives as tributaries, streams so important as the Red River, the Arkansas, the Ohio, the Missouri, and the Illinois. Now the Missouri is itself a river of much greater length, width, and depth than that which above their confluence has been denominated the Upper Mississippi, and if, of two confluent streams, the greater be entitled to be regarded as the continuation of the main stream, the river which is now called the Missouri ought to be denominated the Upper Mississippi.

131. It must not be inferred from what has been here stated that the valley of every river is formed by slopes, having declivities obvious to the eye, or limited by chains of mountains of conspicuous elevation. Most commonly it is quite otherwise, the declivities of the valley being so gentle as to be almost imperceptible, and the summits of the ridges, which limit it, having no elevation which entitles them to the name of mountains.

132. **Portage.**—Where the navigation of a river is impeded by waterfalls, rapids, shallows or other natural obstructions, the space over which goods, and sometimes canoes or boats have to be carried, to meet the navigable part of the stream again, is called a *portage*.

133. **Examples of rivers of North America.**—This division of the western continent being traversed by two ridges, the Rocky Mountains and the Alleghanies, whose general directions are nearly parallel, is divided into three zones, running north and south, the centre and broadest of which is included between the two ridges, the eastern zone sloping down from the Alleghanies to the Atlantic, and the western from the Rocky Mountains to the Pacific.

134. **Eastern rivers.**—The disposition of the general relief of the continent, shown by a section of it, running east and west, determines three different directions for the rivers. Those which are formed of the drainage of the eastern slopes of the Alleghanies, flow eastward into the Atlantic, and the distance of the ridge of the Alleghanies from the Atlantic coast not being great, and the surface of the intervening zone being nearly plane, the lengths of the rivers are inconsiderable, and their streams not rapid.

135. **Western rivers.**—In the same manner the drainage of the western slope of the Rocky Mountains forms a series of rivers which flowing westward fall into the Pacific.

136. **The Mississippi and its tributaries.**—The great extent of the valley included between the ridges of the Alleghanies and the Rocky Mountains, and its great capacity for cultivation, confer upon it an importance which is immensely augmented by the great length through which the rivers which traverse it, are navigable.

137. The drainage of the western slopes of the Alleghanies, and that of the eastern slopes of the Rocky Mountains, form two systems of rivers, the one flowing from west to east, and the other from east to west, and meeting in a common bed in the centre of the valley. They thus form a main stream traversing the valley from north to south, the magnitude of which increases as it descends southwards, in proportion to the number and magnitude of the streams which flow into it from the one side or the other. This central stream is the Mississippi, which gives its name

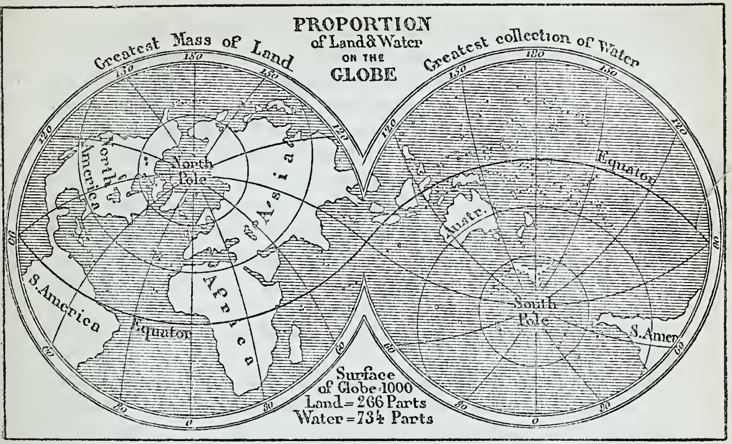
to the entire valley, extending from the Gulf of Mexico, into which its waters fall, to the great northern lakes.

138. **Red River—Arkansas—Ohio.**—New Orleans, which is the port of the Mississippi, is built at the confluence of the arms of its Delta, about one hundred miles above its mouth. Ascending the river from this point, we encounter successively its vast tributaries, the first of which is called the Red River, which flows into it from the slope of the Rocky Mountains upon its right bank. Proceeding upwards, the next is the Arkansas, on the same side, which itself receives at various points of its course subordinate affluents, among which the principal are the Canadian, the Red Fork, the Salt Fork, &c. A little higher, we come to the Ohio, flowing from the east, after having traversed a vast extent of the great valley, and receiving several large tributaries, such as the Cumberland, the Tennessee, the Wabash, &c. The Ohio carries the chief part of the commerce of the states of Tennessee, Kentucky, Virginia, Ohio, Indiana, Illinois, and the western part of Pennsylvania. It washes Pittsburgh, Cincinnati, and Louisville, while its tributaries reach the principal towns of the interior of the adjacent states. It is navigated by steam-boats of the largest class as high as Pittsburgh.

139. **St. Louis.**—Returning to the confluence of the Ohio and the Mississippi, and continuing to ascend the latter river, we arrive at St. Louis, a city of the first importance, and likely one day to become the great capital of the valley of the Mississippi and the western division of the States, with New Orleans for its port. Already we see ranged along its quays hundreds of steam-boats of immense tonnage, which ply incessantly between it and New Orleans, carrying down the stream the produce of the interior, and up, innumerable articles of importation.

140. **Illinois.**—Immediately above St. Louis we arrive at a point marked by the confluence of three streams, one flowing from the north-east, one from the north, and the other from the north-west, the last being the most considerable. The first is the Illinois river; the second, though less considerable than the third, is taken by geographers as the continuance of the main stream of the Mississippi; and the third and greatest is the Missouri, regarded as a tributary of Mississippi.

The Illinois river ascends the state of that name in a north-easterly direction, and is navigable for a considerable distance to a point where it is connected by a canal with Lake Michigan at Chicago. By this means a continuous water-communication is established between New Orleans and the northern lakes, and by those lakes with the St. Lawrence.



VIII.—LAND AND WATER.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER III.

141. Source of Mississippi.—142. Missouri and its tributaries.—143. The Amazons.—144. Its tributaries.—145. The Orinoco.—146. The Rio de la Plata.—147. The river system of Europe.—148. General plan of the rivers of the world. CLIMATE.—149. Determines the animal and vegetable kingdoms.—150. Its dependence on latitude.—151. Explained by the varying positions of the earth.—152. Spring equinox.—153. Sun vertical at equator.—154. Oblique at all other points.—155. Its thermal influence in different latitudes.—156. Position of the earth on 21st June.—157. Days longer than nights in northern hemisphere.—158. Temperature depends on sun's altitude and length of day.—159. Thermal influence greatest on 21st June in northern hemisphere.—160. Position of the earth at autumnal equinox.—161. Why the longest day is not the hottest.—162. Why the summer is warmer than the spring.—163. The Dog-days.—164. Like phenomena in the southern hemisphere.—165. Position of the earth on 21st December.—166. Winter season explained.—167. Why the shortest day is not the coldest.—168. The Tropics.—169. The sun can only be vertical within them.—170. Illustration of the varying position of the earth in the successive months.—171. The arctic polar circles and the frigid zones.—172. Diurnal and nocturnal phenomena which characterise them.—173. The torrid zone.—174. Sun vertical twice a year in the torrid zone.—175. Temperate zone.

141. **Source of Mississippi.**—Ascending the main stream from its point of confluence with the Missouri, after passing several tributaries of less importance, we arrive at the falls of St. Anthony, which constitute the limit of its navigable course. Above these we find its source in a sheet of water, called Lake Istaca, situate near the northern limit of the territory of the United States, and at a short distance west of Lake Superior.

142. **Missouri and its tributaries.**—Returning to the confluence of the Mississippi with the Missouri, and ascending the latter stream, we find innumerable tributaries, variously denominated Smoky-hill-fork, Republican-fork, Platt-river, White-river, Yellow-stone-river, &c., until the stream, reduced to a number of diverging threads, loses itself in the flanks of the Rocky Mountains.

Such is a brief and rapid view of this prodigious vein of inland navigation. As shown in our general plan of the rivers, the total length of the Mississippi and its chief tributary is estimated at 4500 miles.

143. **The Amazons.**—Among the rivers of Southern America, which flow from the western declivities of the chain of the Andes, by far the most important is the Amazons, which, considered merely in its geographical character, ranks as the greatest of rivers. The total length from the mouth to the source of any one of its thousand tributaries, is less than the length of the Mississippi similarly measured, but numerous and large as the tributaries of the latter are, those of the Amazons are still greater in number, width, and depth.

This immense stream, and its countless affluents, drain a vast plain lying between the tableland of Brazil, on the south, and the chain of mountains rising from a similar tableland of less extent, on the north, called the tableland of Paramo. It receives tributaries accordingly from an extensive series of declivities completely surrounding it, from those of Brazil on the south, from the Andes of Peru on the south-west, from the Andes of Quito on the north-west, and from those of the mountain-chains of Paramo on the north.

The plain and surrounding declivities drained by this immense river system, is little less in extent than 3,000000 of square miles, being ten times the magnitude of the French empire. Its largest branch, considered as the commencement of the main stream, is called the Maranon, a name which is sometimes applied to the entire river. The main river and its tributaries are navigable at distances of nearly 2500 miles from its mouth, and its width, near its mouth, being nearly 100 miles, it resembles an arm of the sea more than a river.

144. **The tributaries** of this river are severally so considerable in magnitude and importance, that geographers are not agreed as to which of them should be regarded as the main stream, and the name Amazon is generally confined to the part of the river below the confluence of several chief tributaries, which unite nearly at the point where the Rio Negro or Black River joins the Amazons. A view of a good map of this part of Southern America, will give the reader a more clear idea of the course of this river and its tributaries, than could any mere verbal description. The greater tributaries are above twenty in number, all of which are navigable to a point near their sources, while the lesser ones are countless.

Notwithstanding the geographical superiority of the Amazons, and its vast extent of navigable water, it is inferior in commercial importance to the Mississippi; the districts of country traversed by the river and its branches consisting of tracts of natural forest, and uncleared and uninhabited ground.

145. **The Orinoco,** another of the great rivers of the southern division of the new continent, drains a valley included between the tableland of Paramo, the eastern chain of the Cordilleras, and the plateau of Caraccas. This river, having its source near that of the Negro, flows first north, and then east, discharging its waters into the Atlantic, through a delta, at the borders of the Caribbean sea, opposite the island of Trinidad.

146. **The Rio de la Plata.**—The third great river of South America is that which near its source is called the Parana, and near its mouth the Plata. It discharges its waters into the South Atlantic, at Buenos Ayres, after having flowed down a valley included between the Andes of Chili and the Brazilian mountains. The length of this river is estimated at 2700 miles, and for 200 miles above its mouth it is nowhere less than 170 miles wide.

147. **The River System of Europe** is as inferior to that of the new continent in geographical, as it is superior to it in commercial and social importance. With the exception of some of the lines of river-communication in the United States, the world can afford no parallel for the spectacle of commercial and social movement presented by the European rivers. The gentle declivities of the water-sheds from which they derive their sources, and the general flatness of the plains over which they flow, are eminently favourable to their commercial utility.

In the western division of Europe, the chain of the Alps and the German mountains form the ridge, along the slopes of which, north and south, the waters flow towards the Atlantic on the one side, and the Mediterranean and Black Sea on the other. In the

Rivers of the Eastern Hemisphere.

Rivers of the Western Hemisphere.

eastern division there is no mountain-chain thus to divide the drainage. A slight and imperceptible elevation of the general plain produces two opposite water-sheds, commencing in a low range of hills separating the sources of the Dnieper from those of the Vistula, and winding along the plain to the tableland of Valdai, which forms its summit, 1200 feet above the level of the sea. The ridge then turns northward towards Lake Onega, and, following a winding course, terminates in the Ural Mountains, about 62° N. lat.

The drainage of the north side of this ridge forms the rivers which flow into the Baltic and the White Sea, that of its southern declivity those which flow into the Black Sea and the Caspian.

148. **General Plan of the Rivers of the World.**—The principal rivers of the world, with their tributaries, their embouchures, and their sources, are exhibited in one general plan on the opposite page, where their lengths are indicated.

CLIMATE.

149. Since the prevailing character of the animal and vegetable kingdoms, in each division of the earth's surface, depends chiefly on climate, it is necessary, on that account alone, independent of many other considerations, that the student in geography should be rendered familiar with the conditions, which in each part of the globe determine the varying vicissitudes and temperature of the seasons.

150. **Dependence of Climate on Latitude.**—The first and chief condition which determines the climate of a country, is its position with respect to the equator. It may be stated, subject to some special qualifications, that the nearer any country is to the Line, or what is the same, the lower its latitude, the higher will be the mean temperature of its seasons.

The reason of this is partly geographical and partly astronomical.

The earth revolves diurnally upon an axis, so directed that the equatorial parts are presented either exactly or nearly to the sun. They are presented exactly to that luminary at the epochs of the equinoxes, in March and September. From March to June they are gradually more inclined from the sun towards the south, the northern hemisphere inclining towards that luminary, so as to receive its rays more directly, and in greater quantity than the southern hemisphere. This inclination of the globe increases constantly from March to June, and then decreases from June to September. The northern hemisphere is thus more and more exposed to the light and warmth of the sun, from March to June; the days during that interval are gradually longer and warmer. It is constantly less inclined from June to September; the days during that interval are gradually shorter and less warm.

Hence it is, that in the northern hemisphere the longest days and highest temperature take place after June, the temperature after March being more moderate. The interval between March and June constitutes, therefore, the spring, and the interval between June and September, when the accumulated effects of heat are greater, the summer.

151. This varying position of the earth towards the sun will be rendered more easily intelligible by illustrative diagrams.

Let N S in these four figures represent the axis of the earth, N being the north, and S the south pole. Let E Q at right angles to N S be the equator, and let S′ be the direction of the sun.

152. In fig. 8 is shown the position of the earth on the 21st of March, the day of the spring equinox. The equator E is then presented exactly in the direction of the sun, the light and heat of which are equally distributed between the two hemispheres.

Fig. 8.

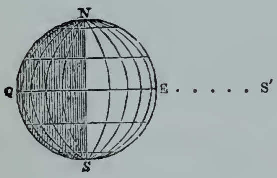
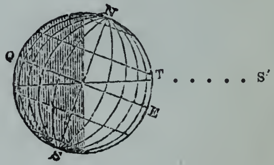
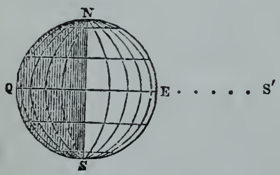


Fig. 9.



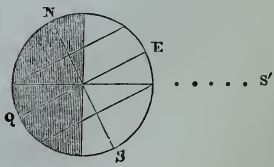
21st June.

Fig. 10.



21st September.

Fig. 11.



21st December.

The boundary of the enlightened hemisphere passes through the poles N and S, and divides into two equal parts all the parallels of latitude. As the earth revolves, therefore, upon its axis, each place upon its surface is during equal intervals exposed to and withdrawn from the sun's light. In other words, the days and nights are equal in all parts of the earth.

153. As the earth turns upon its axis N S, all the places upon the equator E Q are brought successively to the point E, directly under the sun. In other words, at all such places the sun is vertical daily at noon.

154. At all other parts of the earth between E and N, or between E and S, the sun is seen at noon obliquely, or what is the same, it is at a distance greater or less from the zenith. And the more distant the place is from the equator, the more distant will the sun be from the zenith at noon.

155. But since the thermal influence of the sun depends in a great degree upon its proximity to the zenith at noon, it follows that this influence will gradually decrease in going from E to N, or from E to S. The temperature, therefore, of the climate at the time of the equinox will gradually diminish as the latitude increases.

But since any two places at equal distances from the equator, north and south, would be presented towards the sun at noon with equal obliquities, it follows that so far as depends on this circumstance, the thermal influence of the sun at places having equal latitudes north and south, will be the same at the time of the equinoxes.

156. The position of the earth with relation to the sun on the 21st of June is shown in fig. 9. The equator E in the interval between the 21st of March and the 21st of June, has gradually declined to the south. The north pole N has consequently been turned more and more towards the sun S′, and the south pole S has been turned more and more from it. In this position, therefore, it is evident that the sun shines more fully on the northern, and less so on the southern hemisphere. The point T, to which it is vertical at noon, is now, not as in the former case upon the equator, but at the distance of $23\frac{1}{2}°$ north of it. Places in the northern hemisphere above this point are shone upon by the sun at noon with much less obliquity than places having equal latitudes in the southern hemisphere.

157. The circle which bounds the hemisphere of the earth enlightened by the sun, divides all the parallels of latitude unequally, the larger part of those in the northern hemisphere being enlightened, and the larger part of those in the southern hemisphere being dark.

It follows, therefore, that at this time the days are longer than the nights in the northern, and the nights longer than the days in the southern hemisphere.

158. Now the temperature of the seasons, in any given place, depends conjointly on the altitude to which the sun rises, and on the length of the day; for the greater the altitude is, the more

directly will the solar rays fall upon the place; and the longer the day is, the longer will be the interval during which the thermal influence of the sun is exerted, and the shorter will be the interval during which its presence will be withdrawn.

159. For all these reasons, therefore, on the 21st of June, when the northern hemisphere is most inclined towards the sun, and the southern most inclined from it, the thermal influence of the sun will be greater in the northern, and less in the southern hemisphere, than at any time from the 21st of March to the 21st of June.

During this interval the northern hemisphere is gradually more and more inclined towards the sun, and therefore the length of the day is continually increasing, as well as the altitude to which the sun rises at noon. These two circumstances combine in gradually increasing the thermal influence of the sun from the 21st of March to the 21st of June.

The same circumstances will show that during the same interval, the thermal influence of the sun in the southern hemisphere is gradually diminished; the days being there constantly shorter, and the altitude to which the sun rises at noon constantly less.

After the 21st of June the northern hemisphere is gradually less and less inclined towards the sun, and the southern less and less inclined from it, until at length on the 21st of September, the day of the autumnal equinox, the earth resumes the position, fig. 10, with relation to the sun which it had on the 21st of March, the equator E being then, as before, directed exactly towards the sun.

160. The two hemispheres therefore, as in March, being equally exposed to the sun, receive from it the same thermal influence, and the parallels of latitude being all bisected by the circle which bounds the enlightened hemisphere, the days and nights are equal at all parts of the earth.

Since the altitude to which the sun rises, and the length of the days at equal intervals before and after the 21st of June, are the same, and therefore the thermal influence of the sun also the same, it might be inferred that the temperature of the weather would likewise be the same; and if this inference were just, it would follow that the season from the 21st of March to the 21st of June, would be similar in all its thermal characters to the season from the 21st of June to the 21st of September, except that the succession of temperatures would be developed in a contrary order. Thus it would be expected that the temperature of the weather ten or twenty days after the 21st of June would be identical with its temperature ten or twenty days before the 21st of June.

161. But it is notorious that the thermal phenomena are not at all in accordance with this; the season from the 21st of March to the

21st of June, called the Spring, having generally a much lower temperature than the season from the 21st of June to the 21st of September, called the Summer.

Let us see, then, whether we cannot render evident the cause of this.

The temperature of the weather in a given place, depends not exclusively upon the thermal influence exercised by the sun during each day. It must be remembered that when the days are much longer than the nights, and the sun rises to a considerable altitude, a greater quantity of heat is imparted to the atmosphere and to all objects upon the surface during the day, than is lost during the night, and, consequently, an *increment* of heat is given to all such objects every twenty-four hours. The consequence is, that the general effect of the sun's thermal influence during each successive twenty-four hours is to augment the temperature, and thus to increase by accumulation the heat from day to day; and this daily increase will obviously continue until, by the shortening of the days and the decrease of the sun's altitude, the increment of heat during the day becomes equal to its decrement during the night. The day on which that takes place will be the hottest day, because it will be that upon which the daily accumulation will cease. After this, the days being further shortened, and the sun's altitude further diminished, the increment of heat during the day will be less than its decrement during the night, and after each interval of twenty-four hours there will be on the whole a decrease of heat, and so the temperature of the weather will be diminished.

162. Now, from a due consideration of these circumstances, it will be easy to see why the season of summer is warmer than the season of spring, although the sun's altitude and the length of the days are, on the whole, precisely the same both in one season and the other, only succeeding each other in a contrary order. Until the 21st of June the daily thermal influence of the sun continually increases, for the reasons just explained, and it is greater on the 21st of June than on any other day before or after. But although this thermal influence decreases after the 21st of June it is still considerable, and from day to day adds something more or less to the heat already accumulated in the atmosphere, and consequently continues to augment the temperature; and this increase only ceases, when the thermal action of the sun during the day, begins to be counteracted and balanced by the loss of heat during the night.

163. Hence it arises that a certain interval, from the 21st of June to the latter part of July, is generally the hottest part of the summer, being called the *Dog-days*, either because of the

prevalence of canine madness during that period, or because at an early epoch in astronomical history the Dog-star rose before the sun in the morning at that season, and thus harbingered the God of Day. It may even have happened that the Dog-star took its name originally, from the prevalence of canine madness at that season.

164. The circumstances which explain the phenomena of summer in the northern hemisphere, will also explain those of winter during the same interval in the southern hemisphere, since the southern hemisphere at all times is inclined from the sun, exactly as much as the northern hemisphere is inclined towards it, as will be apparent by reference to fig. 9.

165. After the 21st of September (fig. 10), the day of the autumnal equinox, the equator is gradually inclined towards the north, and the northern hemisphere gradually inclined from the sun, and this inclination constantly increases until the 21st of December, when it is greatest, as shown in fig. 11.

The solar rays, as will be apparent from the figure, then fall with greatest obliquity on the northern hemisphere, and with least obliquity on the southern. The parallels of latitude are unequally divided, in both hemispheres, by the circle which bounds the enlightened part of the earth. In the northern hemisphere the greater portions of these parallels are dark, and the lesser portions enlightened, while the contrary takes place in the southern hemisphere. The days are, therefore, shorter than the nights in the northern, and longer in the southern hemisphere; and the sun rises only to low altitudes in the former, but to considerable altitudes in the latter. In fine, all the circumstances show that, in this position of the earth, the summer commences in the southern, and the winter in the northern hemisphere.

166. After the 21st of December, the inclination of the northern hemisphere from the sun gradually and constantly diminishes until the 21st of March, when the equator is once more presented directly to the sun, which affects both hemispheres alike.

Since the 21st of December is the shortest day, and that upon which the sun rises to the least altitude, it is consequently that on which its thermal influence is least, and it might therefore be expected to be the coldest day, and consequently to be mid-winter. It is notorious, on the contrary, that the coldest weather is at a later period. This is explained upon the same principles exactly, as those which show why the 21st of June is not the hottest day.

167. The decrement of heat which takes place in the atmosphere owing to the length of the night, the shortness of the day, and the low altitude of the sun on the 21st of December, is greater

than the decrement on any succeeding day; but still on these succeeding days there is still a decrement of heat, though a less one, and therefore on the whole the temperature must continue to fall, and it will so continue until by the increasing length of the day, and the decreasing length of the night, and the increasing altitude of the sun, the increment of heat during the day becomes equal to its decrement during the night; after that takes place, the result of the sun's influence during each twenty-four hours will be on the whole an increase of heat, and the temperature of the weather will accordingly be augmented.

Hence it is that the winter season in the northern hemisphere is the interval between the 21st of December and the spring equinox; the same interval being the summer season in the southern hemisphere.

The altitude to which the sun rises at noon constantly increases until the 21st of June, when it becomes as it were stationary, and afterwards decreases. In the same manner the altitude at noon constantly decreases until the 21st of December, after which it increases, having remained in like manner stationary for a certain interval. These two epochs have therefore been called the solstices, one being denominated the summer, and the other the winter solstice, from a Latin word which signifies the standing or stationary position of the sun.

168. When the northern hemisphere is most inclined towards the sun, as shown in fig. 9, the sun is vertical at noon to all places at $23\frac{1}{2}°$ north of the equator. Before that day, and after it, the sun's altitude at noon is less than 90°, and consequently it does not reach the zenith. It may be considered therefore gradually to approach the zenith at such places until the 21st of June, and then gradually to recede from it.

From this circumstance the parallel of latitude which passes through such places has been called the *tropic*.

Similar phenomena are produced at the corresponding parallel of south latitude, and these parallels are accordingly called respectively, the northern and southern tropic, or the *Tropic of Cancer* and the *Tropic of Capricorn*.

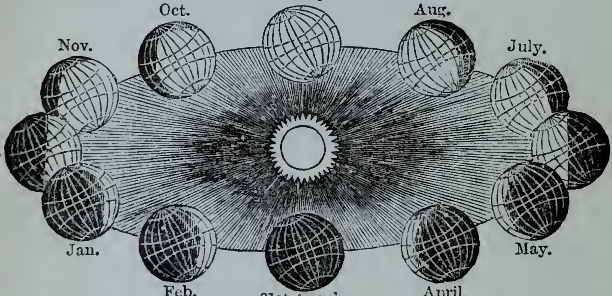
169. It will be evident, by considering the diagrams, fig. 9 and fig. 11, that the sun can never be vertical at noon to any part of the earth except to places which lie between the tropics, and at all such places it is vertical at noon twice in the year.

170. These astronomical causes of the vicissitudes of the seasons may be further illustrated by the diagram, fig. 12, which presents a perspective view of the earth in twelve successive positions which it assumes in one revolution round the sun, the observer being supposed to view it from the north side of the plane of its

orbit. Its motion in that case is in a direction contrary to that of the hands of a clock, or to that of a common screw when turned so as to cause it to move inwards or forwards.

While the globe thus moves round the sun, its axis keeps constantly the same direction, so that in any one position it is

Fig. 12.



parallel to the direction which it had in any other position. On the 21st of June, as shown to the right of the diagram, the northern extremity of the axis, or the north pole, leans towards the sun through an angle of $23\frac{1}{2}°$. If we suppose a parallel of latitude to be described at that distance from the pole, all places within that parallel will receive the light of the sun, and the rotation of the globe on its axis will not throw any of these places upon the dark side of the earth. It follows, therefore, that on the 21st of June the sun does not set at all to any place above that parallel, and there is consequently twenty-four hours day.

By referring to the position of the earth, on the extreme left of the figure, which it has on the 21st of December, it will be seen that then the north pole is inclined from the sun, just as much as it was inclined towards it on the 21st of June, and that the same places, bounded by the parallel of latitude $23\frac{1}{2}°$ from the pole, which on the 21st of June lay altogether on the enlightened side of the globe, and enjoyed twenty-four hours day, now lie on the dark side, and have twenty-four hours night. As the sun never sets to such places on the 21st of June, so it never rises to them on the 21st of December.

In the positions successively assumed by the earth, in July and August, the north pole is less and less inclined towards the sun, and the part around it, which has no sunset, is limited by a less and less parallel of latitude. On the 21st of September, the equator being presented to the sun, there is no part around the pole which has continual day, all places being twelve hours exposed to the sun, and twelve hours removed from it.

After the 21st of September, the north pole begins to incline from the sun, and in October, a small portion around it is entirely deprived of the sun's light. This portion, thus involved in continual night, constantly increases in extent until the 21st of December, when it extends to the parallel of latitude already mentioned. After the 21st of December, the north pole is less and less inclined from the sun, so that the portion involved in continual night is less in January, and still less in February, and on the 21st of March, as on the 21st of September, there are twelve hours day and twelve hours night to all places.

After the 21st of March, the north pole begins again to lean towards the sun, and a portion of the earth around it enjoys continual day, this portion increasing in extent during the months of April and May, and attaining its greatest magnitude on the 21st of June, when its extent, as already explained, is a circle $23\frac{1}{2}°$ from the pole.

171. The parallel which is $23\frac{1}{2}°$ from the pole, is $66\frac{1}{2}°$ from the equator, and consequently has the latitude north of $66\frac{1}{2}°$.

This parallel of latitude is called the *Arctic* or *Polar Circle*, and the polar region included by it is called the *Frigid Zone.*

All the circumstances, which are here explained, respecting the north polar region, circumscribed by the arctic circle, will be equally applicable to the corresponding region, circumscribed by a circle $23\frac{1}{2}°$ from the south pole. Such a circle is called the *South Polar* or *Antarctic Circle*, and the polar region circumscribed by it is the *Southern Frigid Zone.*

172. Although the diurnal and nocturnal phenomena of the two frigid zones, northern and southern, are precisely the same, they are not simultaneous, those which are identical being produced at opposite epochs of the year, as will be rendered evident by examining attentively the several positions of the illuminated and dark hemispheres of the globe in the successive months, in fig. 12. When the entire north polar circle is enlightened on the 21st of June, the entire south polar circle is dark. There is continual day in the one, and continual night in the other. On the contrary, when the entire north polar circle is dark on the 21st of December, the entire south polar circle is enlightened. There is continual night in the one, and continual day in the other.

The phenomena on the 21st of June, therefore, in the northern frigid zone, are identical with those of the 21st of December in the southern frigid zone, and *vice versâ.*

In the like manner, there is just so much of the northern polar region enlightened, and of the southern polar region darkened, in July, as there is of the northern polar region darkened, and the southern enlightened, in January. The diurnal and nocturnal vicissitudes, therefore, of the northern frigid zone in July, are identical with those of the southern frigid zone in January, and *vice versâ.*

If the reader will take the trouble of following the position of the earth from month to month, as shown in fig. 12, he will be able to satisfy himself, that at all intervals of six months the vicissitudes of light and darkness are in the same way reciprocated between the two frigid zones.

It might be inferred, that the continual presence of the sun above the horizon, would necessarily produce a great calorific effect; and at least during that portion of the year, during which they are respectively inclined towards the sun, the polar circles would enjoy intense heat. That such, however, is not the case is easily explained. The heat imparted by the sun to any part of the earth exposed to its influence, depends, as already stated, on two conditions: first, the altitude to which it rises, and secondly, its continuance above the horizon, or the length of the day. But the former condition has a vastly greater influence upon the thermal effects than the latter. Although, therefore, the continuance of the sun above the horizon, at the polar circles, is favourable to the development of heat, yet the very low altitude to which it rises counteracts this effect; so that within the polar circles, even with the influence produced by the continuous presence of the sun, the general temperature is invariably below that at which water freezes.

It is from this continuance of a temperature so low that the frigid zone has taken its name.

173. **Torrid Zone.**—The part of the earth included between the tropical circles, which comprises all places having a latitude less than 23½°, is called the *Torrid Zone.*

Although the exposure of these regions to the heat of the sun varies within certain limits between December and June, being most completely presented to that luminary in March and September, they, nevertheless, receive the solar influence in a much more powerful degree, than the parts of the globe having higher latitudes in the one hemisphere and the other.

It is demonstrated in physics, that the heating power of the sun's rays falling upon any object increases in proportion as they approach to the perpendicular direction upon it. At the time of the equinoxes, therefore, the noon-day sun upon the Line, projecting its rays perpendicularly downwards, produces the greatest possible calorific effect.

At these times, also, the sun, rising precisely in the east, ascends the heavens at right angles to the horizon, until at noon it reaches the zenith; after which it descends perpendicularly in like manner, and sets precisely in the west.

174. **Sun vertical twice a year in the Torrid Zone.**—Every point of the torrid zone is presented, at one period or another of the year, directly to the sun, so that there are two days in the year upon which the sun at noon is vertical at such places, and its extreme departure from the zenith at noon is always very limited. Thus to places on the Line, the sun at noon never departs from the zenith more than $23\frac{1}{2}°$, and even at the limits of the torrid zone, that is, at the latitude $23\frac{1}{2}°$ north or south, the sun which on the 21st of June is vertical at noon in the northern, and on the 21st December in the southern hemisphere, is not more than 47° from the zenith at noon on the 21st of December in the northern, and on the 21st of June in the southern hemisphere; for all places within the tropics the extreme distance of the sun from the zenith at noon must always be less than 47°.

Indeed it may be stated generally, that for places between the tropics, the greatest distance of the sun at noon from the zenith will be found by adding $23\frac{1}{2}°$ to the latitude of the place, and that twice in the year it passes through the zenith at noon.

When it is considered that the temperature of the weather mainly depends on the distance of the sun from the zenith at noon, increasing as that distance decreases, it will be easily understood why the climate of the torrid zone is characterised by that extremely elevated temperature from which it takes its name; for although the sun at noon, during a certain part of the year, is at a distance more or less considerable from the zenith, the interval during which it has this distance is comparatively short, and that during which it is in or near the zenith much more considerable.

The hottest seasons occur, not as might be first supposed, upon the Line, but at and within a limited number of degrees of the tropics; because at such latitudes the sun at midsummer continues to cross the meridian very near to the zenith for a much more considerable time than on the Line at the epochs of the equinoxes, where its change of declination is much more rapid.

175. **Temperate Zone.**—The parts of the globe included between the limits of the torrid and frigid zones,—that is between the latitudes $23\frac{1}{2}°$ and $66\frac{1}{2}°$,—is exempt from the extremes of temperature which characterise the one and the other of these regions. Within its limits the sun never ascends to the zenith, nor on the other hand are the phenomena of continuous day or

continuous night ever witnessed. The warmth of summer is produced by long days, combined with moderate meridian altitudes, and the rigour of winter is mitigated by the presence of the sun above the horizon for a considerable interval, even on the shortest days.

It must not be understood, that within the limits of what is thus called the temperate zone, the climates are uniformly the same. On the contrary, in approaching those limits, at which it is united with the torrid and the frigid zones, the character of the climates approach gradually to those peculiar to the one extreme zone and the other, so that the climates of the higher latitudes of the temperate zone differs but little from those of the lower latitudes of the frigid zone, while those of the lower latitudes of the temperate zone, approximate gradually and insensibly to those of the higher latitudes of the torrid zone. In fact, within the limits of the temperate zone are included a much greater variety of climates than any which characterise either of the extreme zones.

VI.—TURKEY—GREECE.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER IV.

176. Climate, dependent on elevation.—177. Vegetation of the Himalayas.—178. Vegetation of the Andes.—179. Animals of the tropics.—180. The Himalayas—Animals inhabiting them—181. The local character of climate.—182. Heat received from celestial spaces.—183. Why the temperature of the earth is not indefinitely increased.—184. Effect of clouds.—185. Effect of contact of air and earth.—186. Thermal effects of a uniform surface.—187. Why this regularity does not prevail. Mountains.—188. Maps and globes in relief.—189. Johnston's Physical Maps.—190. Mountain ranges not uniform.—191. Spurs.—192. Relief of the earth's surface.—193. Effect of the contemplation of mountain scenery.—194. The Pyrenees.—195. The Alps.—196. Average height of continents.—197. New mountain ranges possible. The Ocean.—198. Greatest depth.—199. Uses of the ocean.—200. General system of evaporation and condensation.—201. Climatic effects.—202. Ocean currents.—203. Antarctic drift current.—204. Its equatorial course.—205. Gulf stream.—206. Course and limits of ocean currents evident.—207. Ocean rich in animal life.—208. Moral impressions.

176. **Climate dependent on elevation. Snow Line.**—It has been explained in our Tract on Terrestrial Heat, that as we ascend into the atmosphere from the level of the sea, the mean temperature gradually decreases, and beyond a certain elevation it falls even below the freezing point of water; above this limit, therefore water cannot exist in the liquid state, and must assume the state of snow or ice. Such an elevation is accordingly designated the limit of perpetual snow, and it is marked on all lofty mountains by the limits of their snow-covered sides. This boundary is accordingly called the *Snow Line.*

It may be stated as a general fact, subject nevertheless to some local qualification, that the elevation of the snow-line is greatest at those parts of the earth, where the climate at the level of the sea is hottest, and that its elevation decreases with the decrease of the mean temperature of the same level. The snow-line, therefore, has the greatest elevation within the tropics, and decreases gradually with the increase of latitude, until at the polar circles it falls to the surface.

Since climate therefore varies, not only with the latitude but with the elevation of the place above the level of the sea, it follows that in mountainous regions a variety of climates will prevail, depending on the elevation of the summits. If that elevation exceed the limits of the snow-line, all varieties of climate between that which characterises the sea level, or which is natural to the plateaux on which the mountains stand, and the climate of the poles are found, and consequently a corresponding variety of natural productions, vegetable and animal, and corresponding susceptibilities of culture prevail. This is a circumstance which gives much interest to mountainous countries, and often confers upon them great commercial and social advantages.

It is evident, also, that the higher the mean temperature of the plateaux is upon which snow-capped mountain ranges stand, the greater will be the varieties of climates exhibited between their summits and their bases, and the greater consequently will be also the variety of natural productions and artificial culture. Hence arises the magnificent display of vegetation exhibited in those ranges of the Andes and Cordilleras, and other lofty ridges which intersect the torrid zone.

177. **Vegetation of the Himalayas.**—Although the chain of the Himalayas far exceeds in elevation the Andes and Cordilleras of South America, they are thus, from their geographical position, being situate far beyond the limits of the torrid zone, excluded from the advantages here noticed, and they present none of that inexhaustible variety of phenomena by which the ridges

which rise to such vast altitudes from the plateaux of the torrid zone are characterised. Beautiful as are the valleys of Kumaoon and Nepaul, they are not signalised by the presence of a single palm-tree. On the southern slope of the Paropamisan range, which extends over 350 miles of Persia and Afghanistan, and separates the deserts of Yezd and Turkestan, Nature nowhere displays that profusion of arborescent grasses, tree-ferns, heliconias, and orchideæ which are witnessed on the higher plateaux of the tropical mountains. On the slopes of the Himalayas, under the shade of the deodar and the large-leaved oak peculiar to these Indian alps, the rocks of granite and mica-schist are clothed with forms closely resembling those which characterise Europe and northern Asia. The species indeed are not identical, but they are similar in their aspect and physiognomy, including junipers, Alpine birches, gentians, parnassias, and prickly species of ribes. The chain of the Himalayas is also wanting in those imposing volcanic phenomena, which in the Andes and the Indian Archipelago often recall to the inhabitants, in characters of terror, the existence of forces developed within the globe. Moreover, on the southern declivity of the Himalayas, where the vapour-loaded atmosphere of Hindostan deposits its moisture, the region of perpetual snow descends to a zone the elevation of which does not exceed 13000 feet. Thus the region of organic life ceases at a limit 3000 feet lower, than that to which it extends in the equinoctial portion of the Cordilleras.

178. **Vegetation of the Andes.**—The mountainous regions of the Tropics present a further advantage in being that part of the globe, as already mentioned, where the greatest possible variety of impressions are produced by the contemplation of nature. In the Andes of Cundinamarca, Quito, and Peru, furrowed by deep barrancas, it is given to man to behold at once all the plants of the earth, and all the stars of the firmament. There, at a single glance, the beholder sees lofty feathered palms, humid forests of bamboos, and all the beautiful family of musaceæ, and, above these tropic forms, oaks, meddlars, wild roses, and umbelliferous plants, as in our European homes. There, too, both the celestial hemispheres are open to his view, and when night arrives, he sees displayed together the constellation of the Southern Cross, the Magellanic clouds, and the guiding stars of the Bear, which circle round the Arctic Pole. There the different climates of the earth, and the vegetable forms of which they determine the succession, are placed one over the other, stage above stage, and the laws of the decrement of heat are indelibly written, on the rocky walls and rapid slopes of the Cordilleras, in characters easily legible to the intelligent observer.

Not only is the torrid zone by the abundance and luxuriance of its organic forms most rich in powerful impressions, but it presents another and greater advantage, in the uniform regularity which characterises the succession of its meteorological and organic changes. The well marked lines of elevation which separate the different forms of vegetable life, demonstrate in a striking manner the same play of general and invariable laws, which govern the celestial motions reflected in terrestrial phenomena. Thus, in the burning plains which stretch nearly on the level of the sea in these regions, we behold in profusion the families of bananas, of cycadaceæ, and of palms, of which the number of species included in the Floras * of the tropical regions, has been so wonderfully augmented by modern botanic travellers. To these succeed, on the slopes of the Cordilleras, in the mountain valleys, and in humid and shaded clefts of the rocks, tree-ferns raising their thick cylindrical stems, and expanding their delicate foliage, whose lace-like indentations are seen projected against the deep azure of the firmament. There, too, flourishes the cinchona, whose fever-healing bark is deemed the more salutary, the oftener the trees are bathed and refreshed by the light mists, which form the upper surface of the lowest stratum of clouds.

Immediately above the region of the forests the ground is covered with white bands of flowering social plants, small aralias, thibaudias, and myrtle-leaved andromedas. The alp-rose of the Andes, the magnificent befaria, forms a purple girdle round the spiry peaks. On reaching the cold and stormy regions of the Paramos, shrubs and herbaceous plants, bearing large and richly-coloured blossoms, gradually disappear, and are succeeded by a uniform mantle of monocotyledonous plants. This is the grassy zone, where vast savannahs clothe the high tablelands and the wide slopes of the Cordilleras, whence they reflect a yellow hue,—savannahs, on which graze llamas and cattle descended from those formerly brought from the Old World. Trachytic rocks next appear forcing the turf and rising high into those strata of the atmosphere containing a less proportion of carbonic acid, and supporting only plants of inferior organisation, such as the lichens, the lecideas, and the many-coloured dust of the lepreria, which forms small round patches on the surface of the stone.

Scattered patches of fresh fallen snow arrest the last feeble traces of vegetation, and are succeeded by the region of perpetual snow, of which the lower limit is distinctly marked, and undergoes but little change.

* The collection of vegetable productions natural to a country is called its *flora*, and that of the animals indigenous to it its *fauna*.

The elastic subterranean forces strive, for the most part in vain, to break through the snow-clad domes which crown the ridges of the Cordilleras, but even where these forces have actually opened a permanent channel of communication with the outer air, either through crevices or circular craters, they rarely send forth currents of lava, erupting more frequently ignited scoriæ, jets of carbonic acid gas, sulphuretted hydrogen, and steam.*

179. **Animals of the tropics.**—A corresponding variety is found in the animal kingdom in these regions at the level of the sea; upon the plains which extend over the tropical regions are found the varieties of monkeys, crocodiles, the boa-constrictor, rattle-snake, jaguars, and macaws. Higher up, at a level rising from 5000 to 10000 feet, at the base of the Andes, are found the ocelot, the strutheo rea, and the duck. Higher still, the ape, the puma, and the llama, and, in fine, about the snow-line, hawks, vultures, bears, and the condor, which rises upon its vast wings above the lofty summits of Chimborazo and Aconcagua.

180. **The Himalayas** are characterised, also, by animals dwelling in a succession of stages one above the other. Thus, upon the plains are found the tiger, the peacock, and the Bactrian camel. Higher up the bat, the Cashmere goat, and the pheasant, and just below the snow-line, the sheep, the yak, the pigeon, the robin, &c.

181. **The local character of a climate** depends on the mean temperature of the atmosphere and of the surface of the earth. And this temperature itself must depend chiefly on the heat imparted to the atmosphere and the earth by the sun. The solar rays, in passing through the atmosphere to the earth, impart to that very attenuated and transparent fluid an inconsiderable quantity of heat, their chief thermal power being exerted on the surface of the earth, which forms the base of the atmospheric ocean. The earth, like all bodies, absorbs a certain proportion of the heat thus transmitted to it, and what it fails to absorb it reflects exactly as a surface would reflect light. The heat which it reflects, not entering it, does not affect its temperature, and it is warmed exclusively by the portion it absorbs. This portion is so considerable, that if it were uniformly diffused over the entire surface of the earth, it would be sufficient to dissolve annually a shell of ice 100 feet thick covering the entire globe.

182. **Heat received from celestial spaces.**—But besides the heat received from the sun, the earth also receives a considerable portion of heat from the surrounding firmament, in other words,

* Humboldt's Cosmos. Introduction.

from the countless myriads of suns composing the stellar universe which are seen nightly sparkling in the heavens; and this latter source of heat differs from that of the sun, inasmuch as all parts of the earth are constantly exposed to it night and day, whereas they are only exposed to the direct influence of the sun during average intervals of twelve hours.

It has resulted from the experiments and observations of M. Pouillet, that the quantity of heat thus received by the earth from the celestial spaces is such, that if it were uniformly diffused over the surface it would be sufficient to melt a shell of ice, enveloping the earth, 85 feet thick.*

183. **Why temperature of the earth is not indefinitely increased.**—It may be asked, therefore, how it happens that if the earth receive and absorb an annual quantity of heat so enormous, its temperature is not raised to such a point as to be incompatible with the continued existence of the organised world upon it. It might be expected that the heat absorbed in the torrid zone, being transmitted by the process of conduction through the solid matter composing the earth to the colder regions of the poles, would first dissolve all the ice there collected, and then gradually raise the temperature of the polar regions, to which the animal world would first take refuge flying from the scorching region of the tropics, and which would become at the same time the theatre of the present flora of the temperate and tropical zones, and later would be raised to a temperature destructive of all organisation.

Such a catastrophe is prevented, and the thermal condition of the globe maintained within the necessary limits, by a remarkable property with which matter has been endowed by its Maker, in virtue of which all bodies possess the quality of thermal radiation, in the exact proportion in which they are endowed with that of thermal absorption. The heat, therefore, which every part of the surface of the earth absorbs from the solar rays, it throws back by the process of superficial radiation, and if the atmosphere were everywhere cloudless, the heat thus radiated back would pass into the celestial spaces, and the atmosphere would then, in spite of the solar rays passing through it, remain at a very low temperature.

184. **Effect of clouds.**—The existence of clouds, however, modifies this. The heat radiated from the surface of the earth is in a great degree intercepted, and prevented from escaping into the celestial regions, by the clouds, which reflect and radiate it back again to the earth through the lower strata of the atmosphere; and thus these thermal rays, being reverberated between the

* See Tract on Terrestrial Heat, Museum, vol. 3, p. 65.

clouds and the surface, warm the lower strata of the atmosphere through which they are so frequently transmitted.

185. **Effect of contact of air and earth.**—But the atmosphere also receives heat from the earth, by the contact of its lowest strata with those parts of the terrestrial surface, which have a higher temperature. When these lowest strata are thus warmed by contact, they ascend as heated air does in a chimney, air having a lower temperature flowing in to take their place.

It is by these several means therefore, much more than by the direct influence of the sun, that the temperature of the atmosphere is maintained and regulated.

186. **Thermal effects of an uniform surface.**—If the whole surface of the earth consisted of one homogeneous material, whether solid or fluid, and were in one uniform condition, its powers of reflection and absorption, and consequently its power of radiation, would be everywhere the same. In that case the thermal influence of the sun, governed by no other conditions than those of its altitude and continuance above the horizon, would necessarily be the same at all points of the same parallel of latitude, since, at all such points, the sun's altitude and the length of the day are necessarily the same. The equator and each parallel of latitude would then be isothermal lines, a word which expresses a line upon the surface of the earth, all points of which have the same mean temperature. Not only would the mean temperatures of all points on the same parallel be the same, but the extreme temperatures of summer and winter would likewise be the same. In other words, all places having the same latitude would, under the conditions supposed, have identically the same climate. They would have the same average annual temperature, and would be subject to the same vicissitudes of seasons.

In comparing parallel with parallel, the average annual temperature, as well as the extremes of the seasons, would regularly increase with the latitude.

187. **Why this regularity does not prevail.**—But the conditions which would produce such climatic phenomena do not exist on the terrestrial surface. Instead of consisting of one uniform material, that surface is diversified,—first, by land and water; and secondly, the land itself is still more diversified in its character, according as it is more or less clothed with vegetation, and even where it is destitute of vegetation, it varies according to the quality of the rocks or other strata which compose its uncovered surface. The reflecting, absorbing, and therefore radiating powers of the land, are infinitely diversified. In general the foliage of vegetation is a powerful radiator, while the naked

soil, or rocks, are comparatively feeble radiators and stronger reflectors. The water of the ocean, which covers three-quarters of the terrestrial surface, is much more uniform in its thermal properties than the land. But even those properties of the ocean are modified by the congelation which takes place on so vast a scale in the frigid zone.

All these circumstances combined, and many others which can only be fully understood by a more profound study of physical geography, render the actual climatic phenomena extremely different from those which would depend on the latitude alone, and which would be developed on a globe the superficial materials of which would be uniform.

The departure of the lines of equal, mean, and extreme temperatures from the parallels of latitude, has been already explained in our Tract upon Terrestrial Heat, and it will not, therefore, be necessary to insist further upon them here.

VII.—INDIA.

MOUNTAINS.

188. **Maps, and Globes in Relief.**—Elementary instruction in geography has been hitherto for the most part limited to the description of the outlines of land and water. The varieties of form depending on relief have been comparatively neglected. This has arisen most probably from the difficulty of presenting to the student visible representations of such forms. Maps and globes, showing in moulded relief the inequalities of the land, have indeed been constructed, and with suitable explanations may be found useful to the teacher and the pupil. Independently, however, of their cost, which is necessarily considerable, they are subject to grave objection, owing to the enormous violation of proportion between the vertical and the horizontal dimensions, which they must necessarily exhibit. It has been explained elsewhere, that the elevation of the most lofty mountain-summits does not exceed the 1600th part of the Earth's diameter, and consequently such a summit, if formed in relief in its just proportion on a 16-inch globe, would be represented by a protuberance not exceeding the hundredth part of an inch. All maps and globes, therefore, presenting the inequalities of the land in moulded relief, must, in order to render them perceptible at all, give the vertical magnitude exorbitantly disproportionate to the horizontal dimensions. When such illustrations are used for the purpose of elementary instruction, the teacher should be careful to impress upon the mind of the pupil this inevitable departure from the natural proportions.

189. **Johnston's Physical Maps.**—The expedient adopted in the physical maps of Mr. A. K. Johnston renders them exempt from this objection, although the same vivid illustration of the superficial inequalities is not presented by them. In these the plains, valleys, and lowlands are coloured green, the elevated plateaux and table-lands brown; and the mountain-ridges and peaks are distinguished by obvious marks indicative of their relative altitudes, the actual heights being marked in numbers of English feet. The sea is also everywhere distinguished from the land by its blue colour. As a physical illustration, these maps are therefore, as I conceive, as perfect as the nature of the subject of instruction allows.

190. **Mountain-ranges not uniform.**—Although each of the great continental systems, which have been already described, is characterised by a certain prevailing direction, it must not be supposed that it follows one uniform and unbroken course, or even that it consists of a single uninterrupted series. They are, on

the contrary, liable to frequent changes of direction, are in many places discontinuous, and are subject to still greater irregularity in both height and width.

191. **Spurs.**—Each main ridge also throws out lateral ramifications at various angles with its general direction, called *spurs*. Those are often themselves considerable chains of mountains, throwing off secondary spurs parallel to the primary chain, or nearly so. These subordinate ranges, intersecting each other at various angles, and broken by valleys and ravines, form a reticulation, which usually covers a vast extent of country stretching out at either side from the base of the principal chain. They decrease gradually in their dimensions, both horizontal and vertical, with their distance from the parent chain. Every one who has visited the country on either side of the ranges of the Alps, the Pyrenees, or Mount Atlas, will be familiar with these features.

192. **Relief of the Earth's surface.**—Considering the Earth as a globe formed of solid matter, subject to superficial inequalities, and partially covered with water, the land must be regarded merely as the more elevated parts rising out of the waters, which, according to the common law of gravitation, are lodged upon the lowest levels. The level parts of the land must be considered as plateaux, table-lands, or terraces formed upon vast mountains, the bases of which are at the bottom of the Ocean.

The mountains, in like manner, which rise from the surface of the land, must be considered as only the highest peaks of those whose bases are established upon the bottom of the deep, and the plains around them, upon which they rest, as merely terraces or plateaux forming steps, as it were, in ascending their acclivities.

In accordance with these views, it is found that systems of mountains, whether they form continued chains, detached groups, or isolated peaks, seldom have their bases upon a low level. On the contrary, the plains upon which they stand are almost always plateaux or tablelands at a considerable altitude above the level of the sea. The heights of mountain-summits being always expressed with relation to the level of the sea, it must therefore be remembered, that in estimating heights above the general level of the plains on which the mountains stand, it is necessary to deduct the heights of such plains from the tabulated heights of the mountains.

That this correction is of importance, will be comprehended when it is remembered, that the heights of the tablelands upon which the great chains of mountains stand, above the level of the sea, varies from 2000 to 12000 feet. Thus, for example, the tabulated altitude of Kunchinjunga, the highest peak of the Himalayas, and indeed the most lofty point hitherto discovered on the globe, is 28178 feet; but the tableland of Thibet, on which it stands, has an altitude of about 11000 feet, so that the height of the peak above the level of the surrounding plain is only 17000 feet.

In like manner, the height of Mont Blanc is 15739 feet, but the height of the Lake of Geneva being 1450 feet, and the base of Mont Blanc being several hundred feet more, it follows that the summit of Mont Blanc cannot be much more than 13000 feet above the level of its base.

From the two examples here given, it will be apparent how little relation the tabulated heights of mountains sometimes have, to the appearance which they would present to an observer. The highest peak of the Himalayas, measured from the level of the sea, is nearly double that of Mont Blanc, and is sometimes therefore described as being a mountain, such as would be produced by piling two like Mont Blanc one upon the other. Such an illustration, nevertheless, is most inappropriate, as appears from what has been just stated, since an observer of Kunchinjunga must necessarily view it from a station about 11000 feet above the level of the sea, while an observer of Mont Blanc can view it from a station less than 2000 feet above that level. Mont Blanc would, therefore, under these circumstances, have nearly as great an apparent height as Kunchinjunga.

193. **Effect of the contemplation of mountain scenery.**—The more the imagination and understanding are impressed with the lofty and massive mountain ranges—as evidences of great terrestrial revolutions which the globe has undergone at distant epochs of its history—as the limits of varying climates—as the lines of separation forming the watersheds of opposite regions—and in fine, as the theatres of peculiar vegetation—the more necessary is it to obtain a correct numerical estimate of their actual volume, so as to demonstrate the comparative minuteness of their mass beside that of the extensive platforms on which they stand.

194. **The Pyrenees.**—Take, for example, the chain of the Pyrenees, the area of whose base and whose mean elevation have been determined with great precision. Let us suppose that this entire mountain mass were spread equally over the whole surface of France, and let it be required to determine what would be the thickness of the stratum which it would then form. Nothing can be more simple than such an arithmetical problem, and the result of its solution is, that the whole surface of France would be raised only 115 feet.

195. **The Alps.**—In like manner, if the chain of the Alps were levelled, and the material composing it uniformly spread over the whole surface of Europe, it would form a stratum only 21⅓ feet thick.

196. **Average height of continents.**—Baron Humboldt, by an elaborate calculation, obtained a pretty exact estimate of the average height of the surface of the land, composing the principal divisions of the world above the level of the sea. He found that the average height of the land in Europe is 670 feet. In North America, 748 feet. In Asia, 1132 feet; and in South America, 1151 feet.

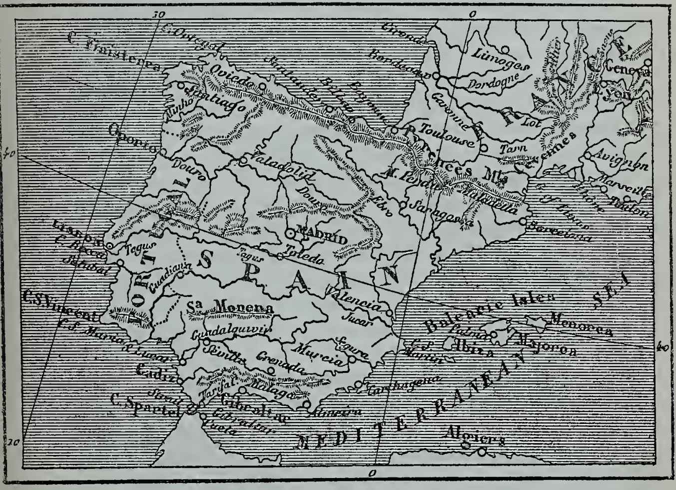
These results demonstrate that the land in the southern regions is more elevated than in the northern. In Asia the low elevation of the extensive plains or steppes of Siberia, is compensated by the mountain masses between the parallels of $28\frac{1}{2}°$ and 40° lat., extending from the Himalaya to the Kuenlun of Northern Thibet, and to the Tianschian or Celestial Mountains. Some idea may be formed from these calculations in what parts of the globe the action of subterranean plutonic forces, as manifested in the upheaval of continental masses, has been most intense.

197. **New mountain ranges possible.**—"There is no sufficient reason," observes Humboldt, "why we should assume that the subterranean forces may not, in ages to come, add new systems of mountains to those which already exist, and of which Elie de Beaumont has studied the directions and relative epochs. Why should we suppose the crust of the earth to be no longer subject to the agency, which has formed the ridges now perceived on its surface? Since Mont Blanc, and Monte Rosa, Sorata, Illimani, and Chimborazo, the colossal summits of the Alps and the Andes are considered to be amongst the most recent elevations, we are by no means at liberty to assume that the upheaving forces have been subject to progressive diminution. On the contrary, all geological phenomena indicate alternate periods of activity and repose; the quiet which we now enjoy is only apparent; the tremblings which still shake the surface in every latitude, and in every species of rock—the progressive elevation of Sweden, and the appearance of new islands of eruption—are far from giving us reason to suppose that our planet has reached a period of entire and final repose."

THE OCEAN.

198. **Greatest depth.**—While the aerial ocean invests the entire surface of the globe, having a depth of from forty to fifty miles, the liquid ocean under it, as already explained, covers only about three-fourths of the solid surface, being deposited according to the laws of gravitation, in the lowest parts. According to the result of soundings, already explained, the character of the solid surface

which it covers is quite analogous to that which rises above its surface, being similarly varied by hill and valley, mountain and plain. The greatest depth of the ocean is still undiscovered. The plumb-line, in one part of the Pacific Ocean, was let down to the depth of 27600 feet by Sir James Ross without finding bottom. It has been generally assumed, as most probable, that the greatest depth of the ocean does not differ much from the greatest elevation of the land above its surface, which being in round numbers five



V.—THE SPANISH PENINSULA.

miles, would show that the extreme difference of level of the solid surface of the globe does not exceed ten miles, or about the 800th part of its diameter.

199. **Uses of the ocean.**—The vast collection of water forming the ocean ministers in an infinite variety of ways to the maintenance of the organised world, and in none more so than in its property of evaporation. It may be considered in a certain sense as a vast apparatus of distillation, by which fresh water is supplied in regulated quantity and suitable quality to all parts of the land, and in these phenomena the mountains play a conspicuous part.

200. **General system of evaporation and condensation.**—It is demonstrated in physics that when an aqueous solution is exposed to the atmosphere, the pure water which forms the chief

part of it will be converted into vapour at the surface in contact with the air; and the rate of such evaporation, other things being the same, will be proportionate to the extent of the surface, the temperature of the air in contact with it, and the superficial temperature of the solution.

The water of the ocean is a solution of certain salts and alkaline substances. The evaporation which takes place from its surface affects only the pure water, leaving the saline and other similar constituents still dissolved in it. The pure aqueous vapour thus taken into the atmosphere, rising to the more elevated strata, is transported by atmospheric currents, and attracted by the mountain summits and other elevated parts of the land, upon which it is precipitated in the form of rain or snow, from which streams flow down the declivities, discharging the functions of irrigation, and thus contributing to the maintenance of animal and vegetable life upon the land.

201. **Climatic effects.**—Independently of the obvious advantages which the ocean affords, as supplying the means of intercommunication by commerce between distant parts of the earth, it also serves an infinite variety of purposes in the climatic economy of the globe. It has been already shown that from the uniformity of its physical qualities, it has a tendency to equalise and regularise climate, so as to bring the isothermal lines into closer proximity with the parallels of latitude.

202. **Ocean currents.**—Its liquid properties, however, combined with the effects of temperature, render it further subservient to the general equalisation of the temperatures of the extreme zones, moderating the heat of the torrid and the cold of the frigid. This is accomplished by the great ocean currents, the existence, directions, and limits of which have been ascertained by modern navigators.

These currents are classed as constant, periodical, and variable, the two latter classes being determined chiefly by the influence of the winds and tides.

203. **Antarctic drift current.**—The constant currents which are by far the most important, have their origin chiefly in the southern frigid zone, from which a vast stream called the *antarctic drift current*, pours its cold waters first northwards into the Pacific and then eastwards towards the eastern coast of South America. Striking upon the shores of Chili, opposite the island of Juan Fernandez, it is diverted to the north, following the coast of the South American continent, until it encounters the jutting shores of Peru, by which it is turned westward, where it takes the name of the equatorial current.

204. **Its equatorial course.**—From that point, following the

direction of the line westward, and passing among the islands of the Indian Archipelago, it traverses the Indian ocean, and sweeping round the Cape of Good Hope, turns northwards along the west coast of Africa, until it encounters the shores of the Gulf of Guinea, which again divert it westward, where it resumes the name of the equatorial current. Traversing the Atlantic, it arrives at the northern coast of South America, and enters the Caribbean Sea through the chain of the West India islands, from which it arrives in the Gulf of Mexico.

205. **Gulf stream.**—In this long course, after cooling the waters of the tropical ocean, its own temperature is at length raised to a high point, and in that thermal state it arrives in the Gulf of Mexico. The direction of the current is there changed by the southern coast of North America, and it issues through the channel between Cuba and Florida, flowing northward along the coast of the United States, and about the 35th degree of latitude turning north-east, it again traverses the Atlantic, dividing its course into two branches, one directed between the British Isles and Iceland to Spitzbergen in the Arctic ocean, and the other by the Azores and Madeira back to the coast of Morocco.

At the point where it issues from the Gulf of Mexico, the current takes the well-known denomination of the *Gulf stream.* Its temperature, as just stated, is so elevated that its existence can readily be determined by navigators by means of the thermometer. It becomes thus a means of transporting to the regions of the northern frigid zone a portion of the tropical heat, so as to produce the equalising effect already mentioned.

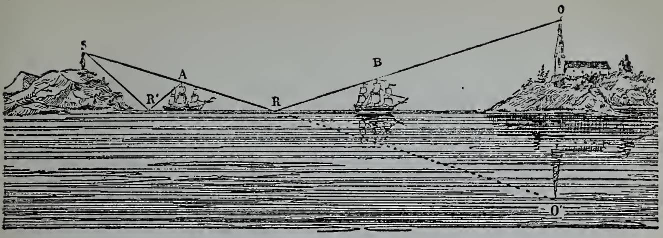
206. **Course and limits of ocean currents evident.**—"The currents of the ocean," observes Humboldt, "present a remarkable spectacle, maintaining a nearly constant breadth. They cross the sea in different directions, like rivers of which the adjacent undisturbed masses of water form the banks. The line of demarcation between the parts in motion, and those in repose, is most strikingly shown in places where long bands of sea-weeds, borne onward by the current, enable us to estimate its velocity. Analogous phenomena are sometimes presented to our notice in the lower strata of the atmosphere, when, after a violent storm, the path of a limited äerial current may be traced through the forest by long lanes of overthrown trees, whilst those on either side remain unscathed."

207. **Ocean rich in animal life.**—Although the surface of the ocean is less rich in animal and vegetable forms than that of continents, yet when its depths are searched, perhaps no other portion of our planet presents such fullness of organic life. Charles Darwin, in the agreeable journal of his extensive voyages,

justly remarks, that our land forests do not harbour so many animals as the low wooded regions of the ocean, where the sea-weed rooted to shoals, or long branches of fuci detached by the force of the waves or currents, and swimming free, upborne by air-cells, unfold their delicate foliage. The application of the microscope still further increases our impression of the profusion of organic life which pervades the recesses of the ocean, since throughout its mass we find animal existence, and at depths exceeding the height of our loftiest mountain chains, the strata of water are alive with polygastric worms, cyclidiæ, and ophrydinæ. Here swarm countless hosts of minute luminiferous animals, mammalia, crustacea, peridinea, and ciliated nereides, which, when attracted to the surface by particular conditions of the weather, convert every wave into a crest of light. The abundance of these minute creatures, and of the animal matter supplied by their rapid decomposition, is such, that the sea water itself becomes a nutritious fluid to many of the larger inhabitants of the ocean.

208. **Moral impressions.**—If all this richness and variety of animal life, containing some highly organised and beautiful forms, is well fitted to afford not only an interesting study, but also a pleasing excitement to the fancy; the imagination is yet more deeply moved, by the impressions of the boundless and immeasurable which every sea voyage affords. He who awakened to the inward exercise of thought, delights to build up an inner world in his own spirit, fills the wide horizon of the open sea with the sublime image of the Infinite; his eye dwells especially on the distant sea line, where air and water join, and where stars rise and set in ever renewed alternations: in such contemplations there mingles as with all human joy, "a breath of sadness and of longing." *

* Humbolt's Cosmos, pp. 299, 303.



SCIENCE AND POETRY.

1. Optical error in the fable of the Dog and the Shadow.—2. Explanation of the phenomena.—3. Table showing the reflection at different obliquities.—4. Effect of looking down in still water over the bulwark of a ship or boat.—5. Effect of the varying distance of the observers.—6. Experiments with a basin of water.—7. Explanation of their effects.—8. Scientific errors in Moore's Irish melody, "Oh, had we some bright little isle."—9. Demonstration of the physical impossibility of what the poet supposes.—10. Allusion in Moore's Irish melody, "Thus when the lamp that lighted," explained. —11. Allusion in Moore's melody, "While gazing on the moon's light."—12. Shakspeare's allusion to the cricket.—13. Moore's allusion to the glowworm.—14. Shakspeare on the economy of the bee.—15. Error of the phrase "blind as a beetle."—16. Lines from Campbell's "Pleasures of Hope."—17. Error of the allusions to the foresight of the ant—Lines from Prior.—18. Verses from the Proverbs. —19. Celebrated description of the war-horse in Job.—20. Unmeaning language of the translation.—21. Examination of the true meaning of the original Hebrew by Dr. McCaul and Professor Marks.—22 Interpretation by Gesenius.—23. By Ewald.—24. By Schultens.—25. Correct meaning explained.

1. In a former Tract we observed, that although the illustrations and images drawn by poets from physical phenomena are generally just and true, yet this is not always the case. They are sometimes altogether at variance with the principles of physics, and involve suppositions totally incompatible with the laws of Nature. The fable of the Dog and the Shadow, which has been handed down through so many ages, diffused through so many languages, and taught so universally in the nursery and in the school, was given as an example of this.*

It was there stated, that this popular fable involved an optical blunder, inasmuch as no reflection which could be supposed to

* See vol. vii., p. 91.

proceed from the water, could possibly be such as to make a real dog behave itself as the dog of the fable did on that occasion. Whether we were fully justified in this condemnation of the ancient fable has been called in question, and some of our readers think that an image may be reflected from the surface of water, under supposable circumstances, with sufficient vividness to justify Æsop, or whoever else was the original author of the fable.

Instead of stopping here to dispute this point, we shall consult the benefit of our readers better by explaining the principles on which it depends, and indicating some simple experiments which we have ourselves tried, and which any of our readers may easily repeat.

2. When light falls upon a plane reflecting surface, the proportion of the rays which are reflected is found by observation to be less and less, the more perpendicularly the rays are incident. The actual proportion reflected at different degrees of obliquity, was determined by Bouguer, for different substances. The results obtained by him in the cases of water and glass are given in the following table, where the angle of incidence means the angle which the incident ray makes with the perpendicular to the reflecting surface. In the fourth column of the table is given for each degree of obliquity the number of rays out of every thousand which are reflected, and in the fifth column, the number which are absorbed.

3. TABLE, *showing the proportion of Light incident on reflecting surfaces, which are regularly reflected at different angles of incidence.*

Specimen of reflecting Surface.	Angle of Incidence.	No. of Rays incident.	No. of Rays regularly reflected.	No. of Rays irregularly reflected and absorbed.
Water	89° 30′	1000	721	279
	75 0′	1000	211	789
	60	1000	65	935
	30 to 0°	1000	18	982
Glass	85	1000	543	457
	75	1000	300	700
	60	1000	112	888
	30 to 0°	1000	25	975

Now it appears from these results, that when a ray falls so obliquely upon the surface of water, as to make with the perpendicular to the surface an angle of 75°, and, therefore, with the surface itself an angle of 15°, nearly a fourth of all the incident rays are reflected. Hence it is that the image of the banks of a lake or river, viewed by an observer (fig., page 193,) stationed at a considerable distance on the opposite side, are very vivid, the rays which produce vision in that case being those which fall with great obliquity on the water.

Since it appears, however, that when the angle of incidence is 60°, and, therefore, the obliquity 30°, less than a fifteenth of the entire number of incident rays are reflected by the water, the image must become fifteen times less vivid. If, therefore, the observer approach the opposite bank, as he may do in a boat, its image reflected in the water will be less and less vivid; or the same effect may be produced in some cases by taking a more elevated position, without changing his distance. Indeed this will give a more accurate result than the former, inasmuch as the change of distance of the eye of the observer from the point of reflection ought strictly to be taken into the account.

If the observer assume such a position, either by increasing his elevation or by diminishing his distance, that the angle of incidence shall be reduced to 30°, and, therefore, the obliquity to 60°, no more than eighteen rays in a thousand will reach the eye; and if the obliquity be still further diminished, the number of reflected rays will be much more inconsiderable.

Thus, by gradually diminishing the obliquity of the incident rays by the change of position of the observer, the reflected image, at first vivid, will be gradually more and more faint, until at length it will cease to be perceptible.

4. If a person look down into still water, over the bulwark of a vessel, he will not perceive any reflected image of his person; but if he lean over the gunwale of a boat, at a much less distance from the surface, he will perceive a faint reflection of his person under certain circumstances. The cause of this is easily explained.

The image formed by reflection is as far behind the reflecting surface as the object is before it, and the intensity of the light proceeding from such an image decreases in the same proportion as the square of its distance from the observer increases. When, therefore, the observer looks over the bulwark of a vessel, the distance of his face from the surface of the water being, for example, 12 feet, the distance of the image formed by reflection is 24 feet. The obliquity of the pencils which, proceeding from his face, are reflected by the water is very small, the rays being nearly perpendicular. Not more, therefore, than about two in every hundred of such rays are reflected to his eye, and these diverge from an image at 24 feet distance. The intensity of such reflected light is, therefore, insufficient to produce a sensible effect on the retina.

When the observer, looking over the gunwale of a boat, is within two feet, for example, of the water, the image produced by the reflected rays is only four feet distant. The intensity of the light is therefore greater, other things being the same, than in the former case, in the proportion of the square of 4 to the square of 24, or what is the same, in the proportion of 36 to 1.

5. But besides this, there is another circumstance to be taken into account. The rays of the pencils which, diverging from the person of the observer, are reflected by the water and received by the eye, have a greater obliquity than in the former case, in the same proportion nearly as that in which the distance of the observer from the surface of the water is diminished, and consequently according to the results given in the above table, a much greater proportion of these rays will be reflected. On both these accounts the image, which was imperceptible from the bulwark of the vessel, is often perceptible from the gunwale of the boat.

In all such observations, however, there are numerous modifying conditions which will vary the result in different cases. Thus, if the water be clear and transparent, and the bottom strongly illuminated, the light reflected from it will often predominate so much over the rays which produce the image to the observer, that this image will cease to be perceptible.

6. We have tried some simple experiments on this subject, the results of which are instructive, and which may be easily repeated by any of our readers.

Fill a basin with water, and place it near an open window, look down from a height of five feet vertically above the surface of the water. You will not perceive any trace of your own image in the water. Descend gradually towards the surface, and when your face is at about four feet above it, the faintest conceivable image of it will begin to be perceived. On approaching still closer, the image will be a little, but a very little, more perceptible, but even at the least distances the reflection will be so faint that it can only be perceived by concentrating the attention upon it.

Let the basin be now surrounded with a sheet or any other expedient, by which the light falling from the window upon the water shall be excluded, but so that your face being above the edge of the sheet shall be still illuminated. You will then perceive your reflected image with tolerable distinctness in the water, even at a distance of four or five feet above its surface, and this distinctness will be increased as the distance of your face above the surface of the water is diminished.

7. The explanation of these effects is obvious. When the water in the basin is exposed to the light of the window, the quantity of the light reflected from the bottom of the basin to the eye of

the observer predominates so much over the reflected rays which form the image of his face, that this image ceases to be sensible; but when by surrounding the basin with a sheet or cloth, all light proceeding from the window is excluded, no light arrives at the eye of the observer except the rays which form the image of his face, which image is therefore distinctly perceivable.

The basin of water may also be instructively applied to illustrate experimentally the results consigned to the above table by Bouguer. If it be placed on the floor or table between the observer and the window, the observer standing at a considerable distance from the basin, the rays proceeding from the window will be strongly reflected from the surface, and a vivid image of the window will be perceived in the usual inverted position in the water. As the observer approaches it, the basin at the same time being moved nearer to the window, the obliquity of the incident rays to the surface of the water is gradually diminished, and the vividness of the image will be found to decrease in a much more rapid proportion, until at length the obliquity is so far diminished that the image becomes altogether insensible.

Whether a reflection under any supposable conditions sufficiently vivid to justify the ancient fable of the Dog and the Shadow is probable, may be questioned, and we do not quarrel with some of our readers who affirm this. We admit that the expressions used by us in paragraph 18, p. 91, vol. 7, may have been too strong if they are understood to imply that in no supposable case could any image whatever be perceivable. We think nevertheless that a dog, looking into a pond with meat in his mouth, the surface of the pond being necessarily exposed to the broad light of day, would not be likely to mistake the exceedingly faint reflection of the meat for another and preferable piece of that aliment.

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8. In one of his Irish Melodies, so familiar to all lovers of poetry and music, Moore has the following lines —

"Oh ! had we some bright little isle of our own,
In a blue summer ocean far off and alone,
Where a leaf never dies in the still blooming bowers,
And the bee banquets on through a whole year of flowers;
Where the sun loves to pause
With so fond a delay,
That the night only draws
A thin veil o'er the day;
Where simply to feel that we breathe, that we live,
Is worth the best joys that life elsewhere can give."

Now this is good poetry, but bad science. An "isle" in which "a leaf never dies," and in which the flowers bloom through the year, must necessarily be within the tropics: a latitude to which the succeeding lines about the "fond delay" of the sun, and the night which only "draws a thin veil o'er the day," which produces, in other words, only a few hours of twilight, are utterly inapplicable.

9. In tropical latitudes the variation of the length of the day is very inconsiderable. It is a little more or a little less than twelve hours, and that is all. The night is, consequently, subject to a variation similarly limited. Instead therefore of the very long days and the very short nights which the poet ascribes to his "isle" in the blue summer ocean, there would necessarily be nights, the duration of which could never be much less than twelve hours in any part of the year.

But this is not all. Instead of enjoying a constant nocturnal twilight, so beautifully described by the poet as a veil drawn over the day, the inhabitants of the tropics enjoy scarcely any twilight at all, being plunged in nocturnal darkness almost immediately after sunset. This arises from astronomical causes, which will be very easily understood.

Twilight is produced by the reflection of the sun's light from that part of the visible atmosphere upon which the sun continues to shine after sunset until its depression below the horizon amounts to about 18°. Now it is apparent, that the more nearly perpendicular to the horizon the diurnal motion of the sun is, the sooner will its orb attain this depression of 18°. In the higher latitudes, where the celestial pole is not very far removed from the zenith, the sun is carried round in a diurnal circle, making a very oblique angle with the horizon; consequently, after it sets, its depression below the horizon increases very slowly, and a long interval elapses before the depression amounts to 18°. In some latitudes at the season of Midsummer it is not so much as 18° even at midnight; and in such places the poet might very truly say,—

"The night only draws
A thin veil o'er the day."

But the latitudes in which this can take place are very different indeed from those in which

"a leaf never dies in the still blooming bowers,
And the bee banquets on through a whole year of flowers."

The distance of the celestial pole from the northern point of the horizon being always equal to the latitude of the place, as may be seen by reference to our Tract on Latitudes and Longitudes, the depression of the sun below the horizon at midnight will be found by subtracting the latitude of the place from the sun's polar distance. Now the sun's polar distance at Midsummer is $66\frac{1}{2}°$, and in order that its depression at midnight should not exceed 18°, the latitude of the place must *at least* be equal to $66\frac{1}{2}°$, diminished by 18°, that is, $48\frac{1}{2}°$.

It follows, therefore, that an entire night of twilight can only take place at latitudes higher than $48\frac{1}{2}°$. But to produce the effect expressed by the poet, a twilight should be maintained much stronger than that characterised by the scientific sense of the term. A twilight which would be only a "thin veil drawn over the day," would be such as can be only witnessed in latitudes like those of Norway and Sweden, the northern parts of Scotland, the Orkneys, &c.

In tropical latitudes, on the contrary, the celestial pole has an altitude less than $23\frac{1}{2}°$, and the diurnal path of the sun makes with the plane of the horizon an angle greater than $66\frac{1}{2}°$. After sunset, the sun therefore descends very rapidly, and the more rapidly the nearer the place is to the line. At the line itself the sun attains the depression of 18° in about seventy-two minutes after sunset; and although the twilight in the scientific sense of the term would not terminate till then, it comes to a close much sooner in the poetic sense of the "veil drawn o'er the day." In short, an almost sudden darkness succeeds sunset, and, in like manner, sunrise succeeds as suddenly to the darkness of night.

In a word, the poet, in the beautiful lines cited above, has combined incompatible astronomical and climatological conditions. The perpetual summer necessarily infers tropical latitude, while the short and twilighted night infers a high, not to say a polar latitude.

It would, perhaps, be deemed hypercritical to examine how far the naturalist would justify the poet in his allusion to the industry of the bee in a tropical climate. The honey-bee, which no doubt was the insect alluded to by the poet, is, for the most part, confined to ultra-tropical latitudes. Since, however, there are certain species of this insect found in the lower latitudes, it may be admitted that the poet has, at least in this point, a *locus standi*.

Having had the pleasure of the personal acquaintance of the author of the Melodies, I once pointed out to him these scientific incompatibilities in his lines. He replied good-humouredly, that it was lucky when he wrote the song that such inconsistencies did not occur to him; for, if they had, some pretty thoughts would inevitably have been spoiled, since he could not have been brought knowingly to take such liberties with the divinities of Astronomy and Geography.

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10. The allusion and imagery which Moore loved to seek in certain parts of physical science were generally much more

consistent with physical truth, without being less beautiful, than that which we have quoted above.

How happily, for example, did he avail himself of that beautiful property of the iris by which it accommodates the eye to greater and less degrees of light, enlarging the pupil when the light is faint, and contracting it when it is intense.

The iris, as is well known, is the coloured ring which surrounds the dark spot in the middle of the eye; this dark spot being not a black substance, but a circular orifice through which the light is admitted to the membrane lining the posterior part of the internal chamber of the eye. This circular orifice is called the pupil, the retina being the nervous membrane which produces the visual perceptions. These, with other particulars of the structure of the eye, will be found fully explained in our Tract on that subject.

The iris which surrounds the pupil has a certain power of contraction and expansion, which is produced by the action upon it of proper muscles provided for that purpose.

The quantity of light admitted through the pupil to the retina is increased or diminished in the proportion of the area of the pupil, which increases and diminishes in proportion to the square of its diameter; a very small variation of which therefore produces a very considerable proportionate variation of the quantity of light admitted.

If a person, after remaining for some time in a room dimly lighted, pass suddenly into one which is strongly illuminated, he will become instantly sensible of pain in the retina, and will involuntarily close his eyes. After a short time, however, he will be enabled to open them and look around with impunity.

The cause of this is easily explained. In the dimly lighted room the pupil was widely expanded to collect the largest quantity possible of the faint light, so that a sufficient quantity might be received by the retina to produce a sensible perception of the surrounding objects. On passing into the strongly illuminated room the expanded pupil admits so much of the intense light as to act painfully on the retina, before there is time for the iris to adjust itself so as to contract the aperture of the pupil. After a short interval, however, this adjustment is made, and the area of the pupil being diminished in the same proportion as the intensity of the light to which it is exposed, has been augmented in passing from the one room to the other, the action upon the retina is proportionally mitigated, so that the eye can regard without pain the surrounding objects.

The reverse of all this takes place when the eye suddenly passes from strong to feeble illumination. The pupil contracted when exposed to the strong light is not sufficiently open to admit the rays of feeble light necessary to produce visual perception, and for some time the surrounding objects are invisible. When, however, the proper muscular apparatus has had time to act upon the iris so as to enlarge the pupil, the rays are admitted in greater quantity, and the surrounding objects begin to be perceived. These phenomena are beautifully expressed by the lines of Moore:—

"Thus when the lamp that lighted
The traveller, at first goes out,
He feels awhile benighted,
And lingers on in fear and doubt;

"But soon the prospect clearing,
In cloudless starlight on he treads,
And finds no lamp so cheering
As that light which Heaven sheds."

Nevertheless there is a point in this which demands some explanation. It is implied in these lines that the source of nocturnal illumination is chiefly, if not exclusively, *starlight*. This has been in a great measure disproved in some memoirs published by Arago in the "Annuaire du Bureau des Longitudes," in which he shows that there must be some other source of nocturnal illumination than that of the stars. On nights, for example, which are thickly clouded there is sometimes a stronger light than on those in which the firmament is clear and serene. From this and other circumstances Arago argues that there must be some power of illumination in the clouds or in the atmosphere independently of the light which proceeds from the stars. This is a point, however, the full development of which would require more space and time than we can spare for it on the present occasion.

---

11. In another of Moore's poems we find the following beautiful lines:—

"While gazing on the moon's light
A moment from her smile I turn'd,
To look at orbs that, more bright,
In lone and distant glory burn'd.
But too far
Each proud star,
For me to feel its warming flame,
Much more dear,
That mild sphere,
Which near our planet smiling came.
* * * *
Thus, Mary, be but thou my own;
While brighter eyes unheeded play,
I'll love those moonlight looks alone,
That bless my home and guide my way."

This is not only beautiful poetry, but sound astronomy. The distances of the stars are many hundreds of millions of times greater than that of the moon, but their actual splendour is in many cases greater than that of the sun. Thus it has been shown by calculations made upon observations which appear to admit of no doubt, that the star Sirius, commonly called the Dog-star, is a sun $146\frac{1}{2}$ times more splendid than that which illuminates our system. Its distance, however, is so enormous that the actual light which it sheds upon our firmament is less than the five thousand millionth part of the sun's light.

Another star, which is the principal one in the constellation of the Centaur, has been ascertained to be a sun whose splendour is $2\frac{1}{3}$ times greater than that of ours, but owing to its enormous distance the light which it sheds in our firmament is twenty-two thousand million times less than that of the sun.*

Sir John Herschel compared the light shed by this star from our firmament, and found by exact photometric measurement that it was 27408 times less than the light of the full moon.

---

12. Shakspeare imputes to the cricket the sense of hearing—

"I will tell it softly, young crickets shall not hear me.

This was long considered as a scientific blunder on the part of the poet, the most eminent naturalists having maintained that insects in general have no sense of hearing. Brunelli, an Italian naturalist, however, has demonstrated that the cricket at least has that sense. Several of these insects, which he shut up in a chamber, continued their usual crinking or chirping the whole day except at moments when he alarmed them by suddenly knocking at the door. The noise always produced a temporary silence on their part. He contrived to imitate their sounds so well that the whole party responded in a chorus, but were instantly silenced on his knocking at the door.

He also made the following experiment. He confined a male cricket on one side of his garden, while he put a female on the other side at liberty. The moment the belle heard the crink of her beau she showed no coyness, but immediately made her way to him.

---

13. The female glowworm, which emits the phosphorescent light, familiar to all who have dwelt in warm climates, remains comparatively stationary to await the approach of her mate, attracted

* Lardner's Astronomy, pp. 749, 752.

to her by the light which she holds out to him, a circumstance of which Moore has availed himself with his usual felicity:—

"Beautiful as is the light
The glowworm hangs out to allure
Her mate to her green bower at night."

---

14. The well-known economy of the bee was never more beautifully described than by Shakspeare, who puts the following comparison into the mouth of the Archbishop of Canterbury:

"True! therefore doth Heaven divide
The state of man in divers functions,
Setting endeavour in continual motion;
To which is fixed, as an aim or butt,
Obedience: for so work the honey bees;
Creatures that, by a rule in nature, teach
The act of order to a peopled kingdom.
They have a king, and officers of sorts:
Where some, like magistrates, correct at home;
Others, like merchants, venture trade abroad;
Others, like soldiers armed in their stings,
Make boot upon the summer's velvet buds;
Which pillage they with merry march bring home
To the tent royal of their emperor!
Who, busied in his majesty, surveys
The singing masons building roofs of gold;
The civil citizens kneading up the honey;
The poor mechanic porters crowding in
Their heavy burdens at his narrow gate;
The sad-eyed justice, with his surly hum,
Delivering o'er to éxecutors pale
The lazy yawning drone."

Henry V., Act. I., Scene 2.

---

15. The phrase "as blind as a beetle," is as false as it is familiar. In the rapid flight of this insect in the evenings of summer, it often strikes the face of those who walk abroad, and hence is erroneously inferred to be blind.

Collins describes this insect in the well-known lines of his Ode to Evening:—

"Now air is hushed, save where
The beetle winds his small but sullen horn,
As oft he rises midst the twilight path,
Against the pilgrim borne in heedless hum."

The poet, it will be observed, avoids falling into the popular error of imputing blindness to the insect.

---

16. In Campbell's immortal poem, the Pleasures of Hope, we find the following lines:—

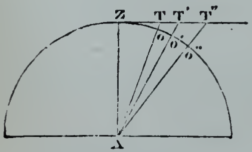
> "Angel of Life! thy glittering wings explore
> Earth's loneliest bounds, and Ocean's wildest shore.
> Lo! to the wintry winds the pilot yields
> His bark careering o'er unfathom'd fields;
> Now on Atlantic waves he rides afar,
> Where Andes, giant of the western star,
> With meteor standard to the winds unfurl'd,
> Looks from his throne of clouds o'er half the world."

Although it is difficult to assign a limit to the degree of exaggeration allowed by the licence of poetry, it is quite clear that there is some such limit, and we apprehend that if these lines, so admirable as poetry, be curiously examined by the light of science, they will scarcely be considered as falling within such limit.

We are to imagine with the poet the genius of the Andes enthroned upon the most lofty peak of that chain, looking round him at the hemisphere, on the middle of which his throne rests. To behold from such a position "half the world," would be a manifest optical impossibility, however elevated his seat might be. But if his range of view could in any degree approximate to half, or even to a quarter of the globe, the exaggeration might be allowed to pass. Let us see, however, what would be the utmost possible range of view which could be obtained by an observer placed upon the apex of the most lofty cone of the Andes, supposing the surrounding mountains of less elevation not to interrupt his general view of the earth's surface.

The most lofty peak of the Andes is that of Aconcagua, which rises immediately above Valparaiso, overlooking the Pacific Ocean. The extreme height of this summit is 23910 feet. Now let us see what would be the extreme range of view from such an elevation; and in making this calculation we shall, contrary to our custom, introduce its mathematical details, so as to inspire our readers with greater confidence in the result. Let us suppose the semicircle here indicated to represent the section of the hemisphere, near the middle of which the summit of the mountain is placed. Let O represent the base, and T the summit of the mountain. If a line T Z be drawn touching the earth, the point Z will be the limit of the range of view of an observer looking from T in the direction of T Z, and the

Fig. 1.



terrestrial arc Z O will therefore represent the radius of the circle round the observer, which will be seen visible to him. In short, it will represent his terrestrial horizon, which the poet in the lines quoted assumes to be half the globe. By calculating the arc Z O, the degree of exaggeration in the poetical illusion will be rendered apparent.

The height of the peak of Aconcagua, reduced to geographical miles, is 3·935. The length, A Z, of the earth's semi-diameter, also expressed in geographical miles, is 3438, and, consequently, of the line A T will be $3438 + 3{\cdot}935 = 3441{\cdot}935$. Let the terrestrial arc Z O be expressed by A, we shall then have

$$\text{Cos. A} = \frac{\text{A Z}}{\text{A T}} = \frac{3438000}{3441935}$$

To compute the value of A, we shall have, therefore—

$$\text{Log. } 3438000 = 6.5363059$$
$$\text{Log. } 3441935 = 6{\cdot}5368021$$

$$\text{Log. Cos. A} = 9{\cdot}9995038$$

$$\text{A} = 2^\circ\ 44'\ 18'' = 164{\cdot}3 \text{ miles.}$$

It appears, therefore, that the range of view round such an observer would be confined within a radius of 164 geographical miles, whereas "half the world," supposing it to be spread out in a circle under the eye of the observer, would be measured by a radius of 90×60, or 5400 miles, so that half the world would be measured by a radius more than thirty-two times that which would actually limit the view of Campbell's "giant of the western star." We admit, however, that the task is rather an ungracious one, which consists in thus cutting down the splendid imagery of Campbell's poetry to the level of the severe limits of scientific truth, and if we do so, it is more for the sake of exercising our readers in physical enquiry, and habituating them to mathematical precision, than with any intention of depreciating poetic beauties of which we are as sensible as others.

---

17. No notion is more prevalent, respecting the insect economy, nor more frequently embodied in the imagery of poets and in the eloquence of moralists, than the industry and foresight imputed to the ant:—

—"Tell me, why the ant,
'Midst summer's plenty, thinks of winter's want,
By constant journies careful to prepare
Her stores, and, bringing home the corny ear,

By what instruction does she bite the grain,
Lest, hid in earth, and taking root again,
It might elude the foresight of her care?"
PRIOR.

It has been ascertained, however, that these instincts are erroneously imputed to the ant. That insect passes the winter in a torpid state, and does not lay up any store of provisions. Still less does it take any such precautions as those commonly imputed to it, of biting off the ends of the grains which it lays in store, to prevent them from germinating. It is supposed that this error may have arisen from the insect being observed to carry about their young in the pupa state, in which they have some resemblance to a grain of corn, and also from their being observed to gnaw off the end of the sheath which encloses the pupa, in order to liberate the insect, after it has attained its perfect state, from its confinement.

18. The words of Solomon respecting this insect, which occur in Proverbs, vi. 6, 7, 8, are well known:—

6. Go to the ant, thou sluggard; consider her ways and be wise.
7. Which having no guide, overseer, or ruler,
8. Provideth her meat in the summer, *and* gathereth her food in the harvest.

If the original Hebrew word, which has been here translated by the Saxon ant, properly signifies the European insect of that name, these verses of Solomon would undoubtedly involve an error in zoological history; but that cannot be affirmed until the habits and manners of other species of the insect inhabiting warmer climates have been examined and ascertained. For although during the cold winters incidental to this climate, the ants remaining in a torpid state do not need food, yet in warmer regions, where they are probably confined to their nests during the rainy season, a store of provisions may be necessary for them. This supposition has been to a great extent verified by the discovery made by Colonel Sykes, at Poonah, in India, of a species of ant, which he denominates *Atta providens*, which store up the seeds of a kind of grass called *panicum*, at the time they are ripe in January and February, which they expose on the outside of their nests to the sun in the warm season, for the purpose of drying them after they have been wetted by the rains of the Monsoon. Such measures cannot be explained, except by the supposition that these seeds are destined for food, and though there is no recorded instance of ants feeding on any vegetable substances, except such as are saccharine, yet, all experience proves how constantly in entomology, exceptions to general laws are presented, and there seems to be good reason to believe that this is one of them.*

---

19. Every reader who is duly sensible of the sublime poetry of certain parts of the Hebrew Scriptures will be familiar with the following splendid description of the war-horse in the Book of Job, xxxix. 19 :—

19. Hast thou given the horse strength ? hast thou clothed his neck with thunder ?

20. Canst thou make him afraid as a grasshopper ? the glory of his nostrils *is* terrible.

21. He paweth in the valley, and rejoiceth in his strength : he goeth on to meet the armed men.

22. He mocketh at fear, and is not affrighted ; neither turneth he back from the sword.

23. The quiver rattleth against him, the glittering spear and the shield.

24. He swalloweth the ground with fierceness and rage ; neither believeth he that *it is* the sound of the trumpet.

52. He saith among the trumpets, Ha, ha ; and he smelleth the battle afar off, the thunder of the captains, and the shouting.

20. In reading these verses, one is so dazzled with their splendour that it is difficult to submit them to the cold test of physical truth. Nevertheless, it has always appeared to us, that the second member of the first verse above quoted is, as translated, destitute of all meaning. To clothe an object with thunder would be to clothe it with a sound, which obviously is destitute of all meaning either literal or metaphorical. It might seem as though the allusion intended in the original of the passage might have been to lightning and not to thunder. One can conceive the waving and flashing of the mane of the war-horse fairly enough imaged by lightning, especially when considered in connection with the roar of the battle-field and "the thunder of the captains," so finely described in a succeeding verse. If the original Hebrew term which has been translated by the word thunder could bear the signification of lightning, the objection here advanced would be removed.

To say that a thing is clothed with a sound reminds one of an anecdote to which we have alluded on a former occasion. A blind man being asked what idea he had of the colour scarlet, replied that he believed he had a very clear notion of it, for that it was just like the sound of a trumpet.

21. Thinking it highly probable that the blemish which I have

* Trans. Ent. Soc., London. Vol. ii. p. 211.

here indicated was attributable to the translators, rather than the author, of the book of Job, I have had recourse to the original Hebrew; and desiring on such a point to be supported by higher authority than I can myself lay claim to, I requested the aid of two eminent Hebraists, Dr. Alexander McCaul, of King's College, and the Rev. Professor Marks, of University College, London, both of whom have favoured me with their opinions and suggestions on the subject; and, as they do not materially differ, there can be no doubt that their interpretation is substantially correct. It appears, as I anticipated, that the translation is faulty; but, on the other hand, the Hebrew word which has been translated thunder never means lightning.

22. Gesenius says that the primitive sense of the term used is tremor, or trembling, being derived from the verb Raam, which signifies to tremble. In verse 19, he says, that it has the primary sense, tremor, and that it is used poetically for the mane of a horse, as in the Greek φόβη. Here, however, are his words from the Thesaurus:

"רַעְמָה f. 1, *tremor;* poet. pro juba equi, quæ in equis nobilioribus propter cervicis obesitatem contremiscit, unde gr. φόβη, juba, a φόβος. (Job. xxxix. 19.)"

23. The famous Ewald, the other great authority in Hebrew, in his "Poetische Bücher des Alten-Bundes," gives the same sense, and translates the word by the German Zittern, trembling. Both understand the trembling mane, and therefore find no allusion to thunder or lightning. The word is by none interpreted *lightning*, and cannot have that meaning. The LXX have φόβον, tremor, which Gesenius supposes to be equivalent to φόβη, mane. Symmachus has κλαγγήν. Theodotion, χρεμετισμόν, which sense is also given by the Vulgate, Hinnitum. The moderns, who prefer this sense, take "neck" as poetic for "throat," or explain the thunder of the sound of the long shaking mane.

24. Schultens translates the word "tremore alacri," (with rapid quivering). Parkhurst translates the word thus, "With the shaking mane."

25. On the whole, therefore, it appears that the English version of the second member of v. 19, chap. xxxix. is incorrect. "Hast thou clothed his neck with thunder?" is not the sense of the original Hebrew, which would be correctly rendered thus, "Hast thou clothed his neck with a shaking (or flowing) mane?"

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ITS CHARACTER AND MANNERS.

STEAM NAVIGATION.

THUNDER AND LIGHTNING, AND THE AURORA BOREALIS.

ELECTRO-MOTIVE POWER.

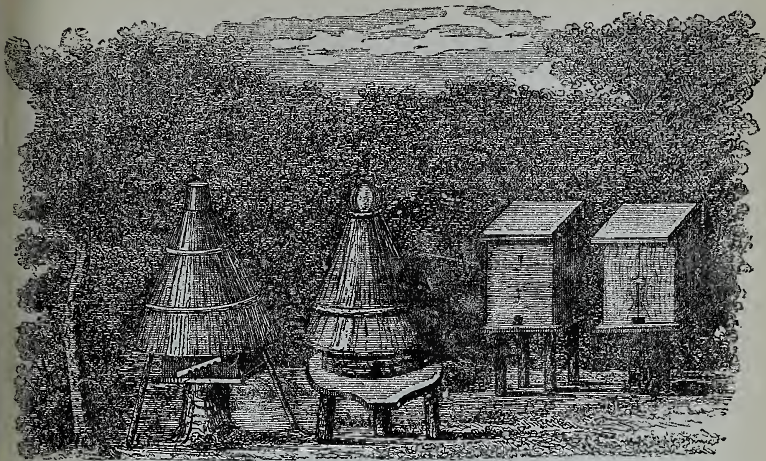


Fig. 54.—Uncovered Apiary.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER I.

1. Moral suggested by economy of nature.—2. Antiquity of apiarian researches—Hebrew scriptures—Aristomachus—Philiscus—Aristotle—Virgil.—3. Modern observers.—4. Huber.—5. His servant Burnens—curious history of his blindness.—6. His wife and son.—7. Pursuit of his researches.—8. Structure of insects.—9. Plan of their anatomy.—10. Hymenoptera.—11. Varieties of bees.—12. Hive bee.—13. The queen—her numerous suitors.—14. Her chastity and fidelity.—15. Her fertility.—16. Her first laying.—17. Royal eggs.—18. Royal chamber.—19. Effect of her postponement of her nuptials.—20. The drones.—21. The workers.—22. Structure and members of the bee.—23. Mouth and appendages.—24. Use of proboscis.—25. Structure of tongue.—26. Honey-bag.—27. Stomach.—28. Antennæ.—29. Wings.—30. Legs.—31. Feet.—32. Sting.—33. Organs of fecundation and reproduction.—34. Number of eggs produced by the queen.

1. Nature offers herself to human contemplation under no aspects so fascinating, as those in which she renders manifest the provident care of the Creator for the well-being of his creatures. The spectacle of infinite wisdom directing infinite power to bound-

less beneficence, never fails to excite in well-constituted minds the most pleasurable and grateful emotions. Such views of Nature are the truest and purest fountains of that reverential love, which so eminently distinguishes the Christian from all other forms of worship.

In the notices from time to time given in this series of the stupendous works of creation presented in the heavens, and of the benevolent care displayed in the supply of the physical wants of the inhabitants, not of the terrestrial globe * alone, but also of the planets,† which, in company with the earth, revolve round the sun, numerous examples of such beneficence are presented. The vast dimensions of these works, as well as the great importance and the countless numbers of the objects to be provided for, leading the mind naturally to expect a system of provisions established on a corresponding scale, their display, while it excites equal admiration and reverence, produces a less intense sentiment of wonder. When, however, we turn our view from the vast works of creation exhibited in the celestial regions, to the more minute ones presented in the organised world around us, our wonder is as much excited as our admiration, at beholding the same traces of Divine care in the economy of an insect, as were observed in the structure and motions of a planet. There are the same infinite wisdom and foresight, the same unapproachable skill, the same boundless goodness directed to the maintenance of the species and the well-being of the individual, as we have seen displayed in the provisions for a globe a thousand times larger than the earth, or for a cluster of worlds millions of times more numerous than the entire solar system, sun, earth, planets, moons, and all! We have thus before us a demonstration that as the most stupendous works of the universe—the expression of whose dimensions surpasses the powers of arithmetic—are not above Divine control and superintendence, so neither are the most insignificant of creatures—whose existence and structure can be made evident only by the microscope—below the same benevolent care.

2. Among the numerous examples, suggestive of reflections such as these, presented by the insect-world, there is none more remarkable than the little creature, to the character and economy of which we shall devote this notice. How true this is, is proved by the examples of those who, in all ages of the world, have devoted their labours to the observation and investigation of its character and habits. In the Hebrew Scriptures numerous allusions to the bee show that, in those remote times, it had already

* See Tracts on the Earth, Geography, Terrestrial Heat, Air, Water, &c.
† See the Planets, are they inhabited ? the Sun, the Moon, the Stellar Universe, &c.

been a subject of attention with the wisest and the best. Pliny relates that Aristomachus of Soli in Cilicia devoted fifty-eight years of his life to the study of the bee; and that Philiscus, the Thracian, passed so large a part of his time in the woods observing its habits, that he acquired the title of AGRIUS. Among his numerous researches in natural history, Aristotle assigned a considerable share to the bee; and Virgil devoted to it the fourth book of his Georgics:—

> "Protenus aërii mellis cœlestia dona
> Exsequar. Hanc etiam, Mæcenas, adspice partem.
> Admiranda tibi levium spectacula rerum,
> Magnanimosque duces, totiusque ordine gentis
> Mores, et studia, et populos, et prælia dicam.
> In tenui labor; at tenuis non gloria, si quem
> Numina læva sinunt, auditque vocatus Apollo."
>
> GEORG. IV. 1—7.

> "The gifts of Heaven my following song pursues,
> Aërial honey, and ambrosial dews.
> Mæcenas, read this other part that sings
> Embattled squadrons and advent'rous kings—
> Their arms, their arts, their manners, I disclose,
> And how they war and whence the people rose.
> Slight is the subject, but the praise not small
> If Heaven assist, and Phœbus hear my call."
>
> DRYDEN.

3. In modern times the bee has been the subject of the observations and researches of some of the most eminent naturalists, among whom may be mentioned Swammerdam (1670), Maraldi (1712), Ray, Reaumur (1740), Linnæus, Bennet, Schirach, John Hunter, Huber—father and son,—and more recently Kirby, whose monograph upon the English bees may be regarded as a classic in natural history.

4. Among these, the elder Huber stands pre-eminent, not only for the extent and importance of his contributions to the history of the insect, but for the remarkable circumstances and difficulties under which his researches were prosecuted. Visited with the privation of sight at the early age of seventeen, his observations were made with the eyes and his experiments performed with the hands of others; and, notwithstanding this discouragement and obstacles which might well have been regarded as insurmountable, he continued his labours for forty years, during which he made those discoveries which have conferred upon him such celebrity.

5. Happily for science, Huber, after losing his sight and at the commencement of his researches, had in his service a domestic, named François Burnens, a native of the Pays de Vaud, in Switzerland. Reading and writing constituted the extent of the

education of this person; but nature had bestowed upon him faculties which, with better opportunities, would have rendered him an eminent naturalist. Huber commenced by employing him as a reader.

He read to his master various works on physics, and, among others, those of Reaumur, in which the admirable observations of that naturalist on the bee are so clearly and beautifully stated. Huber soon perceived by the observations and reflections of his reader, and by the consequences he deduced from what he read, that he had at his disposition no ordinary person, and resolved to profit by him. He accordingly procured the means of prosecuting a series of observations on the economy of the bee, with the aid of the eyes, the hands, and the intelligence of Burnens. All the observations of Reaumur were first repeated, and the accordance of the phenomena, as described by Burnens, with those which had been recorded by Reaumur, gave Huber full confidence; and the master and servant, quitting the beaten path, entered upon new ground, and during a period of fifteen years, prosecuted those researches in the natural history and economy of the bee, which, being committed to writing by the hand of Burnens at the dictation of Huber, were published in one volume about 1792, in form of letters addressed by Huber to Bonnet.

6. Soon after this, Huber lost his invaluable colleague, for servant he had long ceased to be. Burnens was recalled by family ties to his native place, where the personal estimation in which he was held caused him to be raised to a high position in the local magistracy.

Previously to this, Huber had the good fortune to consolidate his domestic happiness by marriage. "My separation from my faithful and zealous Burnens," said Huber, "which was not the least cruel of the misfortunes with which I was visited, was, however, softened by the satisfaction which I felt in observing Nature through the eyes of the being who was dearest to me, and with whom I could commune with pleasure on the most elevated topics. But what more than all the rest contributed to attach me to natural history, was the taste manifested by my son for that subject. I explained to him the results of my observations and researches. He expressed the regret he felt that labours which would, as it seemed to him, so deeply interest naturalists should remain buried in my portfolio. Perceiving, meanwhile, the secret repugnance that I felt against the task of reducing them to order, he proposed to take charge of that labour."

7. From that time our great naturalist was again consoled, by having at his disposal two pair of eyes in place of one. The wife and the son, animated by a common enthusiasm, and urged by

conjugal and filial devotion, more than compensated for the loss of Burnens; and the observations and researches were pursued with unabated zeal, and were finally collected and published in the second volume, which appeared about 1814, more than twenty years after the publication of the first.*

8. Since any explanation, however popular and familiar, of the economy and habits of the bee, must necessarily involve very frequent references to its structure and organs, it will be convenient in the first instance briefly to explain the terms, by which naturalists have designated its several parts.

The body of insects in general consists of a series of annular segments, so articulated one to another as to allow more or less flexibility. It consists of three chief parts, the *head*, the *thorax*, and the *abdomen*.

The head consists of a simple segment, the thorax of three, and the abdomen of a greater number, sometimes as many as nine. Each segment is distinguished by its ventral or inferior, and dorsal or superior part.

Insects have three pairs of legs, which are inserted in the sides of the ventral parts of the three thoracic segments of the body; and generally two pairs of wings, which are inserted in the sides of the dorsal parts of the second and third thoracic segments, counting from the anterior to the posterior part of the body.

A pair of members, called *antennæ*, are inserted in the sides of the head, varying much in structure in different classes, and in many, including the bee, have the form of slender and flexible horns, consisting of many minute pieces articulated one to another. These are generally presumed to be tactile organs, and are consequently sometimes called *feelers*.

9. This description will be more easily comprehended by reference to the annexed diagram, fig. 1, which may be taken as a general theoretical representation of the structure of an insect.

As here indicated, the three thoracic segments are distinguished as the pro-, meso-, and metathorax.

10. Insects have been classified by naturalists according to the structure of their wings, and the order to which the bee has been assigned, and of which it is regarded as the type, is the *Hymenoptera*, a compound of two Greek words signifying membranaceous wings.

The section or subsection of the order of Hymenoptera, which in its economy and peculiar construction differs most from all other orders of insects, has been designated by Latreille *Mellifera*,

* "Nouvelles Observations sur les Abeilles." Paris, 1814.

a Latin word signifying HONEY-GATHERERS; or *Anthophila*, a Greek word signifying FLOWER-LOVERS.

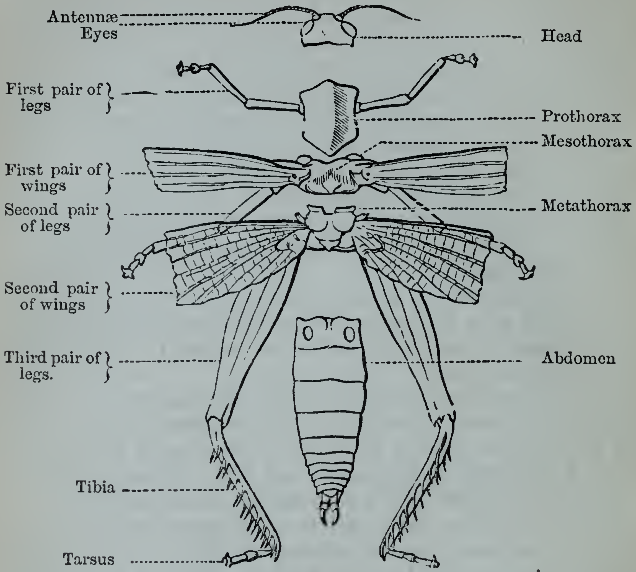


Fig. 1.

11. How numerous are the varieties of bees may be conceived, when it is stated that of bees found in Great Britain alone, Kirby in his Monograph has enumerated 220 species, and other more recent observers have increased the number to 250. The species, however, which by its commercial importance, as well as by its remarkable habits and social organisation, presents the greatest interest, is the Hive Bee, to which, therefore, we shall chiefly limit our notice.

12. The Hive bee belongs to what naturalists have denominated the perfect societies of insects. Each community of these insects consists of three orders of individuals distinguished by their number, their organisation, and the respective share they take in the common labour of the society. These are denominated severally the *queen* or sovereign, the males or *drones*, and the *workers;* the latter consisting of two classes, called the *wax-makers* and the *nurses*. A hive which contains as many as 50000 bees will have only one queen, and not above 2000 males.

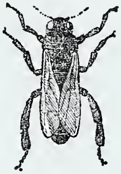
13. The *queen* who, as her title implies, is the acknowledged

monarch of the hive, is distinguished from her subjects by conspicuous personal peculiarities. Her body, fig. 2, is considerably

Fig. 2.

Queen.

Fig. 3.



Drone.

Fig. 4.

Wax-maker.

Fig. 5.

Nurse, loaded with pollen.

Fig. 6.

Drone in flight, showing organs of fecundation.

longer than that of any of her subjects; she is distinguished by a more measured and majestic gait, by the comparative shortness of her wings, and the curvature of her sting. Her wings, which are strong and sinewy, are only half the length of her body, extending very little beyond the posterior limit of her thorax, while those of the drones, fig. 3, and the workers, fig. 4, cover the abdomen. Her legs are destitute of the brushes and baskets with which those of the workers are furnished. She has no occasion for these instruments of industry, since her exalted station exempts her from labour, all her wants being munificently provided for by her subjects. She is distinguished by her colour as much as by her form, the black of the dorsal part of her body being much brighter than that of the drones and workers, and the ventral parts and legs being of dark orange or copper-colour, the hue of the hinder being deeper than that of the other legs.

The queen, who is the only lady of the hive, enjoys the privilege of being followed by many hundred suitors in the persons of the drones. At the early age of two or three days she is marriageable, and it rarely happens that her royal decision is long postponed; and, indeed, if she were not favourably disposed for such an event, the anxiety of her numerous subjects would urge her to it, for in no human monarchy are the hopes of succession so anxiously cherished as in the Empire of the Hive.

14. It must not be imagined, that because a lady is thus domesticated alone with so many hundred lovers, there is any the least degree of laxity in the morals of the society; on the contrary, although she is absolutely uncontrolled, and is courted by so many hundreds, her choice is strictly limited to one. A fine warm sunny day is selected for the nuptials, which are celebrated in the air. On the auspicious occasion, her majesty issuing from the hive followed by the multitude of her suitors, rises in the air, where she is encircled by the flight of the candidates for her favour. Here she makes her selection, but, alas! the felicity is brief, for the object of her choice never outlives the wedding-day. She is, however, not the less faithful to him, and never contracts a second marriage.

15. Though her majesty is thus left a widowed bride, in two days after the celebration of her nuptials and the loss of her lord, she commences to lay eggs from which a posthumous progeny of that lord, countless in number, are destined to issue. Of the hundreds of rejected suitors, a limited number emigrate with the successive swarms, which from time to time leave the overpeopled hive. Those which remain, being no longer useful to the community, become objects of general aversion, and are finally exterminated by a general massacre, as will presently be more fully explained.

16. During six or eight weeks the queen constantly lays eggs, from which working bees only are destined to issue. Chambers have been previously prepared for these, suitable to the future young ones, in form, size, and position, by the workers. In each of those cells the queen deposits a single egg.

At a later period her majesty begins to lay another kind of egg, from which males will issue. For these also special chambers have been provided by the careful workers, of suitable dimensions, being somewhat more roomy than those prepared for worker-eggs. The number of these male eggs and of the cells for their reception is incomparably less than those of the workers; less, in short, in the proportion in which the drone class is less numerous than that of the workers in the population of the hive.

17. In fine, the queen, sensible of her mortality, and moreover of the approaching state of superabundant population in the hive, lays a certain small number of royal eggs, from which as many princesses issue, who are severally destined to be candidates for the thrones of the colonies which are to emigrate, or to succeed to the throne of the hive itself, should the queen-mother, as often

happens, decide on abdicating and accepting the allegiance of one or other of the emigrating colonies.

18. Special chambers of exceptional form, position and magnitude have been previously prepared for these royal eggs by the provident workers. In these the princesses are reared and educated with extraordinary care, being fed with a peculiar food.

19. It is essential to the prosperity of the community, that the nuptials of the queen should not be postponed to a later period than the second day of her age, the consequence of such postponement being that her progeny would consist of a redundancy of drones. Thus, if the marriage be postponed till she is about a fortnight old, she will lay as many drone as worker-eggs, and if it be delayed until her age is three weeks, she will only lay drone eggs. How great a calamity such events must be in the apiarian economy will be understood, when it is considered that in a well-regulated society there ought to be about ten workers to each drone. The general duration of the life of a queen is from five to six years.

20. The males or drones, fig. 3, are less than the queen and larger than the workers, fig. 4. The extremity of the body is more velvety. The last segment being fringed with hair, extending over the tail, so as to be visible to the naked eye. They take no part whatever in the labours of the community, contribute nothing to the common stock, are idle, slothful, and cowardly, and, as if to render their extermination more easy to the industrious part of the population, nature has given them no sting. They make a louder buzz with their wings in flight, never exercise any industry, and are destitute of the baskets and other appendages with which the busy workers collect the materials of honey and wax.

The life of a drone does not exceed a few months, and he seldom dies a natural death. If he is honoured by the choice of the queen and elevated to the rank of king-consort, he dies on the very day of the nuptials. If he be among the hundreds rejected by her majesty, and do not emigrate with one or other of the swarms, being a useless and idle member of the community, he is massacred by the workers.

21. The workers, sometimes called neuters, are generally considered as sterile females. The number of these in each community is very variable, being seldom less than 12000, more generally amounting to 20000, and in hives where swarming is checked by affording abundance of room, the number may rise to 60000. They are the smallest members of the society, fig. 4, have a long flexible proboscis and legs of peculiar structure.

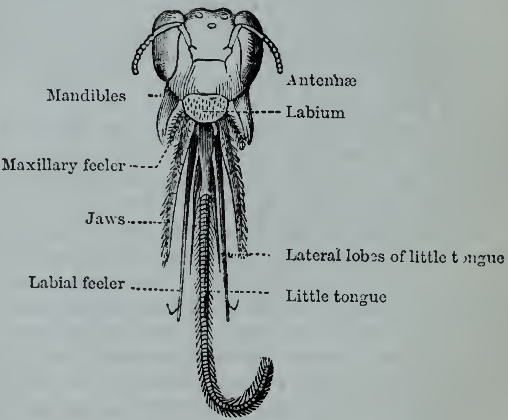
22. Among the wonders presented by the insect-world the *head* of the bee and its appendages command especial attention.

In common with insects generally, the chief parts of the mouth are, the *tongue*, the *jaws*, the *lips*, and the *throat* or œsophagus.

The jaws are each double, separated by a vertical division. Each pair opens, therefore, with a horizontal instead of a vertical movement like the human jaws. The pair of upper jaws are called *mandibles*, and the lower *maxillæ*. The upper lip is called the *labrum* and the lower the *labium*. The mouth is also supplied with two pairs of special organs called *palpi* or feelers, one pair attached to the lower lip and called *labipalpi*, and the other to the lower jaw and called *maxipalpi*.

23. In fig. 7, is given a magnified view of the buccal apparatus of the wild bee (*Anthophora retusa*),* the parts being indicated.

Fig. 7.



A less detailed view, also magnified, of the same apparatus of the hive-bee is shown in fig. 8.

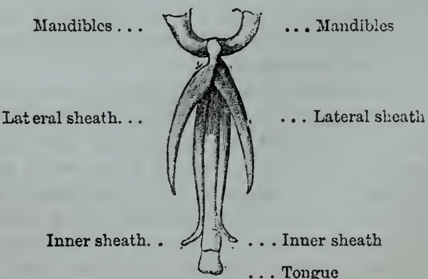


Fig. 8.—Tongue of Hive bee (magnified).

* Milne Edwards.

A magnified view of the head of the drone is shown in fig. 9.

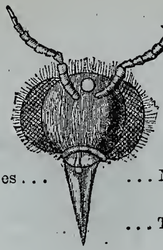


Fig. 9.—Head of a Drone (magnified).

The mandibles, or upper pair of jaws, in the workers are strong, horny and sharp. They are the tools with which it performs its various labours. Meeting over the other parts of the mouth, they are covered in front by the labrum or upper lip. The maxillæ, or lower jaws, on the contrary are pliable and leathery, and hold the objects upon which the insect works with its mandibles.

The tongue, which is long and endowed with great flexibility, is moved by a complex system of powerful muscles. When it is in a state of inaction, it is withdrawn within its sheaths, the end which protrudes beyond them being doubled up under the head and neck, the sheaths consisting of two pair of strong scales.

24. When the bee lights upon the blossom of a flower from which it desires to extract the nectar, it darts out its tongue from the sheaths that invest it, and having pierced the petals and stamina where the treasure is hidden, it inserts its tongue which moves about in every direction in virtue of its great flexibility and muscular power, and probes to the very bottom the floral cells, sweeping their surfaces and draining them to the last drop of their precious juice. Having thus collected the nectar upon the tongue, that organ being drawn back into the mouth, the liquid sweets are projected back into the pharynx, and thence into the throat or œsophagus.

Fig. 10.—Worker extracting nectar from a blossom.

25. It must be observed also, that the tongue is not only flexible but susceptible of inflation, so as to form a sort of bag,* in which

* Dr. Bevan on the Honey Bee, p. 298.

the nectar is collected preparatory to being transferred to the œsophagus.

26. The first stomach or honey-bag into which the nectar

Fig. 11.—Digestive apparatus of the Bee (magnified).

passes through the œsophagus,—which is a long and slender tube passing from the back of the mouth through the neck,—has the form of a Florence flask, and is composed of a material as transparent as glass. When filled it has the magnitude of a small pea. The honey received by it is partly regurgitated and deposited for general use in the cells of the comb, which will presently be described. The remainder which constitutes the food of the insect passes into the true stomach, and from thence into the intestines where it undergoes the process of digestion, the products of which are distributed through suitable tubes to all parts of the body for its nourishment.

27. Both the honey-bag and the stomach are susceptible of contraction, by which the food is thrown back from the former into the mouth as in ruminating animals, and from the latter into the intestines.

28. The antennæ are organs of great importance, upon the functions of which, however, naturalists are not fully agreed. It appears certain nevertheless, that they are not only tactile instruments of great sensitiveness, but are organs, by the signs, gestures, and mutual contact of which the bees communicate to each other their mutual wants, and convey information in many cases, some of which will be noticed hereafter, respecting the condition of the hive.

29. The flying-apparatus of the bee, as well as that of many other insects, far exceeds in power the instruments of flight with which the swiftest birds are furnished. To the anterior margin of the under wings are attached eighteen or twenty hooks, which when spread for flight (figs. 5, 6) lay hold of the posterior edges of the upper wings, so that the two wings on each side thus united act as a single wing.

30. The three pairs of legs are composed of several joints (fig. 1) articulated like those of the human arm, so as to give great mobility to the member. The lower joints of the two under pairs form brushes, the hairs of which are stiff and bristly, and set upon their inner surfaces. The farina which they collect from the stamina of flowers is swept off by these brushes, as well as by the hairs with which their abdomen and thorax are covered. This farina is afterwards by means of the maxillæ or jaws, and the feet of the anterior pair of legs, rolled into pellets and packed in a pair of spoon-shaped cavities or baskets, provided for that purpose and attached to the feet of the hindmost pair of legs. In this process the brushes, after disposing of their own collection of farina, sweep that flour also from the surface of the abdomen and thorax, and pack it in like manner in the baskets. The exterior of these baskets is smooth and glossy, and the interior lined with strong close hairs to retain the load in its place, and prevent its escape in flight.

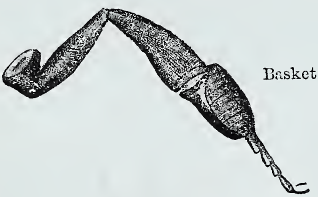


Fig. 12.—Posterior leg of a worker.

It is worthy of remark that neither the queen nor the drones are supplied with this appendage. Since neither exercise any industry they would have no use for it.

31. Each foot terminates in two hooks, the points of which are opposed one to the other. By means of these the insects suspend themselves at will to the sides and roofs of their habitation, and hanging from each other form a living curtain in certain operations which will be presently noticed.

In the middle of each of these is placed the *sucker*, by which the insect is enabled to walk with facility on surfaces with its body downwards, as we see flies walk on ceilings. These suckers are little flexible cups, the edges of which are serrated so as to allow of their close application to any kind of surface. When closely applied, the air between the sucker and the surface is excluded, so that the body is attached to the surface by the pressure of the atmosphere. When the foot is to be detached from the surface, as in walking, the air is readmitted. This apparatus may be easily seen, and its action observed, by inspecting with a microscope the feet of a fly walking on a pane of glass, the observer being on the side of the pane opposite to that on which the fly moves.

32. Besides the stomach and intestines, the abdomen of the queen and workers contains the sting and the apparatus connected with it, by which the venom which it pours into the wound is secreted, an instrument of offence supplied to these in common with many other species of four-winged insects. This formidable weapon of vengeance is established in its tail. All the insects which in common with the bee are supplied with a sting, belong to the order hymenoptera or membrane-winged. This weapon consists of two darts finer than a hair, which lie in juxtaposition, being barbed on the outer sides, but so minutely that the points can only be seen with the microscope. These darts move in the groove of a strong sheath, which is often mistaken for the sting itself. When the dart enters the flesh, a drop of subtle venom, secreted by a peculiar gland, is ejected through the sheath and deposited in the wound. This poison produces considerable tumefaction, attended with very acute pain.

The posterior extremity of the body of a worker with the sting protruded is shown in fig. 13.

Fig. 13.—Posterior extremity of the body of a worker with the sting protruded.

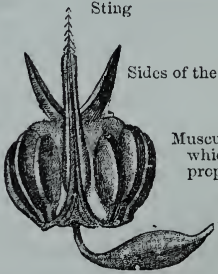


Fig. 14.—The same slightly magnified, showing the venom-bag.

The sheath of the sting, also called the ovipositor, consists, according to Dr. Bevan, of a long tube, or rather of several tubes, which pass one into another like those of a telescope. The muscles by which the sting is propelled, though too minute to be seen without the microscope, have, nevertheless, sufficient power to drive the sting to the depth of the twelfth of an inch into the thick cuticle of a man's hand. The sting is articulated by thirteen scales to the posterior extremity of the body, and at its root are the pair of glands, one of which appears in fig. 14, in which the poison is secreted. These glands, communicating by a common duct with the groove formed by the junction of the lower parts of the barbed sting, send the venomous liquid through that groove into the wound. On each dart there are four barbs. When the insect intends to sting, one of these piercers having its point a little longer, or more in advance than the others, is first darted into the flesh, and being fixed there by its barb, the other strikes in also; and they alternately penetrate deeper and deeper, till they acquire a firm hold of the flesh with the barbed hooks, and then follows the sheath, enclosing and conveying the poison into the wound. The action of the sting thus, as Paley observed, affords an example of the union of chemical and mechanical principles: of chemistry, in respect to the venom; and of mechanism, in the motion into the flesh. The machinery would have been comparatively useless, had it not been for the chemical process by which in the body of the insect honey is converted into poison; and, on the other hand, the poison would have been ineffectual without an instrument to wound, and a syringe to inject it.

In consequence of the barbed form of the sting, and the strong hold it takes on the flesh, the bee can seldom withdraw it, and in detaching herself from the part stung she generally leaves behind her not only the sting itself, but the venom-bag and a part of her intestines. Swammerdam mentions a case in which even the stomach of the insect was torn from the abdomen in detaching herself, so that in most cases her life is the sacrifice for the gratification of her vengeance.

Although the bee, except in certain cases to be mentioned hereafter, uses its sting only in defence, or for vengeance, when molested, it is sometimes found that it manifests an antipathy to particular individuals, whom it attacks and wounds without provocation.

33. The organs of fecundation and reproduction are also contained in the abdomen. Those of the drone are represented on a magnified scale in fig. 15. They correspond in their functions to those of the superior animals.

Fig. 15.—Apparatus of fecundation of the drone.

The organs of reproduction of the queen, which are objects of considerable interest, are shown on a magnified scale in fig. 16.

34. We have already stated that the king-consort never survives the bridal day. As this does not affect the conjugal fidelity

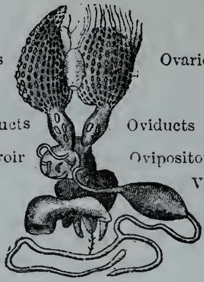


Fig. 16.—Ovaries of the queen and their appendages.

of her majesty, who never allows a successor to her departed lord, so neither does it impose any limit to the posthumous offspring which she bears to him. Small as are the ovaries, or egg organs, which are shown highly magnified in fig. 16, her majesty, according to Huber, generally produces from them about 12000 eggs in the short interval of two months, being at the average rate of 200 per day.

Although her majesty does not continue so prolific during the remainder of her life, she nevertheless gives birth to a progeny enormous in number. The number of eggs deposited by her in the cells in the months of April and May is, as above stated, about 12000. According to Schirach, a prolific queen will lay in a season—that is, from April to October inclusive—from 70000 to 100000 eggs. This amazing power of reproduction is not exerted uniformly during the season. There are two fits, so to speak, of fruitfulness. The first in April and May; the second, in August and September, with an interval of comparative repose in July. This immense increase of population, rendering emigration indispensable, the over-peopled hive sends forth swarm after swarm so fast as the young arrive at maturity; and with each swarm one of the princesses goes forth, and is elevated to the throne of the new colony, except in the event of the abdication of the queen-mother, in which case she emigrates herself, resigning the sovereignty of the hive to one or other of the princesses.

Fig. 76.—Hiving a swarm.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER II.

35. This fecundity not anomalous.—36. Bee architecture.—37. Social condition of a people indicated by their buildings.—38. This test applied to the bee. — 39. Individual and collective habits. — 40. Solitary bees.—41. Structure of their nests.—42. Situation of nests. — 43. Anthidium manicatum. — 44. Expedient for keeping nest warm.—45. Clothier bee.—46. Carpenter bee.—47. Mason bee.—48. Expedient to protect the nest.—49. Upholsterer bee.—50. Hangings and carpets of her rooms.—51. Leaf-cutter bees.—52. Method of making their nest.—53. Process of cutting the leaves.—54. Hive-bee.—55. Structure of the comb.—56. Double layer of cells.—57. Pyramidal bases.—58. Illustrative figures.—59. Single cells.—60. Combination of cells.—61. Great advantages of hexagonal form.—62. Economy of space and material.—63. Solidity of structure.—64. Geometrical problem of the comb solved.—65. Expedient to secure the sides and bases of the cells.

35. The prodigious fecundity of the queen of the bees is by no means an anomaly in the insect world. The female of the white ants produces eggs at the rate of one per second, or 3600 per hour, or 86400 per day. Now, although this insect certainly does not

lay at this rate all the year round, yet, taking the lowest estimate of the period of her reproduction, the number of her young will probably exceed not only that of the queen bee, but that of any other known animal.*

36. There is nothing in the economy of the bee more truly wonderful, nor more calculated to excite our profound veneration of the beneficent power, which conferred upon it the faculties which guide its conduct, than the measures which it takes for the construction of its dwelling, and for those of its young. These processes are very various, according to the particular species of the insect which executes them. Now, most of these species differ in the mechanical and architectural principles upon which they base the construction of their dwellings, all agreeing, nevertheless, in this, that they select those principles with admirable skill, adapting them in all cases to the situation and circumstances in which their habitations are erected.

37. If we would form an estimate of the civilisation and intellectual condition of the population of a newly-discovered country, we usually direct our attention, as Kirby observes, to their buildings and other examples of architectural skill. If we find them like the wretched inhabitants of Van Diemen's land, without other abodes than natural caverns, or miserable penthouses of bark, we at once regard them as ignorant and unhumanised. If, like the South Sea islanders, they live in houses of timber thatched with leaves, and supplied with various utensils, we place them much higher in the scale. But when we discover a nation inhabiting towns like the ancient Mexicans, consisting of stone houses regularly arranged in streets, we do not hesitate to pronounce them advanced to a considerable point in civilisation.

If, moreover, it be found that each building has been constructed upon the most profound mathematical principles, so that the materials have been applied under such conditions as ensure the greatest degree of strength, combined with the greatest degree of lightness; and that, while the internal apartments display the most beautiful symmetry, they also afford the greatest capacity which a given amount of materials can admit, we at once arrive at the conclusion that such a population must have arrived not alone at the highest degree of civilisation, but at the highest point in the advancement of the sciences.

38. If we were to affirm that all this may be said with the most rigorous truth of many varieties of the bee, and above all of the common hive-bee, we might be suspected of being merely excited by that enthusiasm so common with those, who devote

* See Tract on the White Ants.

themselves exclusively to one particular pursuit. We must, nevertheless, leave the reader to judge how far such a statement is chargeable with the exaggeration of enthusiasm, when he shall have duly pondered upon all that we shall explain to him in the following pages; and if, perchance, his wonder be raised to the point of incredulity, that sentiment will be repressed when he remembers, *who taught the bee!*

39. Bees, like the human race, sometimes exercise their industry individually and sometimes collectively. Their habitations also are sometimes constructed exclusively for their young, and may be called *nests* rather than *dwellings*. This is more especially the case with solitary insects. In the case of social bees, which live together in organised communities, the habitations are generally adapted as well for the members of the colony themselves, as for their progeny.

40. The operations of these solitary insects, though exhibiting, as will presently appear, marvellous skill, are infinitely inferior to those of the social bees. We shall, therefore, first notice the more simple labours of the former.

41. Among the most inartificial structures executed by the solitary species, are the habitations of the *colletes succinctæ*, *fodiens*, &c. The situation chosen in these cases is either a bank of dry earth, or the cavities of mud walls. A cylindrical hole pierced in a horizontal direction about two inches in length is first produced. The bee makes in this three or four thimble-shaped cells, each of which is about a sixth of an inch in diameter and half an inch long, fitting one into another like thimbles. The materials of these cells is a silky membrane resembling gold-beater's leaf, but much finer, and so very thin and transparent that the form and colour of any enclosed object can be seen through it. This material is secreted by the insect. When the first of these cells is completed, the insect deposits in it an egg and fills it with a pasty substance, which is a mixture of pollen and honey. When this is done she proceeds to form the second cell, inserting its end in the mouth of the first as above described, and in like manner lays an egg in it and deposits with it a like store of food for the future young. This goes on until the cylindrical hole receives three or four cells which nearly fill it. The bee then carefully stops up the mouth of the hole with earth.

42. The situations in which these simple nests are placed are very various. They are not only found as above stated in banks of earth and mud walls, and the interstices of stone walls, but often also in the branches of trees. Thus a series of them was found by Grew in the pith of an old elder branch.

43. Some varieties of the bee, such as the *anthidium manicatum*, dispense with the labour of boring the cylindrical holes above

described, and avail themselves of the ready-made cavities of trees, or any other object which answers their purpose. Kirby mentions the example of nests of this kind found by himself and others, constructed in the inside of the lock of a garden-gate.

44. A proceeding has been ascertained on the part of these insects in such cases, which it is extremely difficult to ascribe to mere instinct, independent of some intelligence. Wherever the nest may be constructed, the due preservation of the young requires that until they attain the perfect state, their temperature should be maintained at a certain point. So long as the material surrounding their nest is a very imperfect conductor of heat, as earth or the pith of wood is, the heat developed by the insect, being confined, is sufficient to maintain its temperature at the requisite point. But if, perchance, the mother-bee select for her nest any such locality as that of the lock of a gate, the metal, being a good conductor of heat, would speedily dissipate the animal heat developed by the insect, and thus reduce its temperature to a point incompatible with the continuance of its existence. How then does the tender mother, foreseeing this, and consequently informed by some power of the physical quality peculiar to the metal surrounding the nest, provide against it? How, we may ask, would a scientific human architect prevent such an eventuality? He would seek for a suitable material which is a non-conductor of heat and would surround the nest with it. In fact the very thing has occurred in a like case in relation to steam-engine boilers. The economy of fuel there rendered it quite as necessary to confine the heat developed in the furnace, as it is to confine that which is developed in the natural economy of the pupa of the bee. The expedient therefore resorted to is to invest the boiler in a thick coating of a sort of felt, made for the purpose, which is almost a non-conductor of heat. A casing of sawdust is also used in Cornwall for a like purpose. By these expedients the escape of heat from the external surface of the boiler is prevented.

45. The bee keeps its pupa warm by an expedient so exactly similar, that we must suppose that she has been guided either by her own knowledge, or by a power that commands all knowledge, in her operations. She seeks certain woolly leaved plants, such as the stachys lanata or the agrostemma coronaria, and with her mandibles scrapes off the wool. She rolls this into little balls, and carrying it to the nest, sticks it on the external surface by means of a plaster, composed of honey and pollen, with which she previously coats it. Thus invested, the cells become impervious to heat, and consequently all the heat developed by the little animal is confined within them.

This curious habit of swathing up its pupa in a kind of warm blanket has given to these species the name of *clothiers*.

46. Another class of bees has acquired the name of *carpenters*, from the manner in which they carve out their nest in wood-work. This bee, which is represented in fig. 17, and of which the nest is shown in fig. 18, having been already described in our Tract on Instinct and Intelligence (72), need not be noticed further here.

Fig. 17.—The Carpenter Bee. (Xylacope).

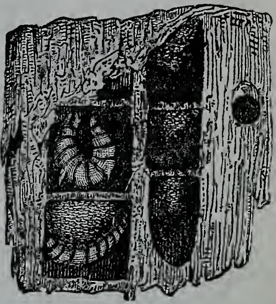


Fig. 18.—Nest of the Carpenter Bee.

47. Another class of this insect has acquired the name of *masons*, from the circumstance of building their nests of a sort of artificial stone. The situation selected is usually a stone wall, having a southern aspect, and sheltered on either side by some angular projection. The situation being decided upon, the mother-bee proceeds to collect the materials for the mansion, which consist of sand, with some mixture of earth. These she glues together, grain by grain, with a cement composed of viscid saliva, which she secretes. Having formed this material into little masses, like the grains of small shot, she transports them with her mandibles to the place where she has laid the foundation of her mansion.

With a number of these masses, united together by an excellent cement secreted by her organs, she first lays the foundation of the building. She next raises the walls of a cell about an inch in length, and half an inch broad, resembling in form a thimble. In this she deposits an egg, fills it with a mixture of pollen and honey, in the same manner as described in the former case, and after carefully covering it in, proceeds to the erection of a second building of the same kind, which she furnishes in the same manner, and so continues until she has completed from four to eight.

These cells are not placed in any regular order; some are parallel, others perpendicular, and others inclined to the wall at different angles. The whole mass is consolidated by filling up the irregular interstitial spaces between the cells, with the same material as that of which the walls are built. After this has been accomplished, the whole is covered up with coarser grains of sand.

The nest when thus finished resembles a mass of solid stone, so hard as to be cut with much difficulty by a knife. Its form is an irregular oblong, and to a casual observer presents the appearance of a mere splash of mud rather than that of a regular structure.

The insects are sometimes so sparing of their labour, that they avail themselves of old nests when they can find them, and often have desperate combats to seize and retain possession of them.

48. It might be imagined that nests so solidly constructed would afford perfect protection to the young from its enemies; such is nevertheless not found to be the case. The ichneumon and the beetle both contrive occasionally to deposit their eggs in the cells, the larvæ of which never fail to devour their inhabitants.

Different varieties of the masons select different situations and materials for their nests. Some use fine earth, which they make into mortar with gluten. Others mix sandy earth with chalk. Some construct their nests in chalk-pits, others in the cavities ot large stones, while others bore holes for them in rotten wood. Wherever placed they endeavour to conceal them, by plastering or covering them with some material different from that of which the nest is constructed. Thus one species surrounds its nest with oak-leaves glued to its surface. M. Goureau mentions the case of a bee that employed an entire day, in arranging blades of grass about two inches long, in the form of the top of a tent over the mouth of its nest. A case of this sort was also observed by Mr. Thwaites, who saw a female for a considerable time collecting small blades of grass, which she laid over the empty shell of a snail in which she had located her nest.

49. The name of *upholsterers* has been given by Kirby to certain species of bees, who, having excavated their nest in the earth, hang its walls with a splendid coating of flowers and leaves. One of the most interesting of these varieties is the *megachile papaveris*, which has been described by Reaumur. It chooses invariably for the hangings of its apartments the most brilliant scarlet, selecting as its material the petals of the wild poppy, which the insect dexterously cuts into the proper form.

50. Her first process is to excavate in some pathway a burrow cylindrical at the entrance, but enlarged as it descends, the depth being about three inches. After having polished the walls, she next flies to a neighbouring field, where she cuts out the oval

parts of the poppy blossoms, and seizing them between her hind legs returns with them to her cell. Sometimes it happens that the flower from which she cuts these, being but half blown, has a wrinkled petal. In that case she spreads out the folds, and smoothes away the wrinkles, and if she finds that the pieces are too large to fit the vacant spaces on the walls of her little room, she soon reduces them to suitable dimensions, by cutting off all the superfluous parts with her mandibles. In hanging the walls with this brilliant tapestry she begins at the bottom, and gradually ascends to the roof. She carpets in the same manner the surface of the ground round the margin of the orifice. The floor is rendered warm sometimes by three or four layers of carpeting, but never has less than two.

Our little upholsterer having thus completed the hangings of her apartment, fills it with a mixture of pollen and honey to the height of about half an inch. She then lays an egg in it, and wraps over the poppy lining, so that even the roof may be furnished with this material. Having accomplished this she closes the mouth of the nest.*

51. It is not every insect of this class which manifests the same showy taste in the colours of their furniture. The species called *leaf-cutters* hang their walls in the same way, not with the blossoms but the leaves of trees, and more particularly those of the rose-tree. They differ also from the upholsterer, described above, in the external structure of their nests, which are formed in much longer cylindrical holes, and consist of a series of thimble-shaped cells, composed of leaves most curiously convoluted. We are indebted likewise to Reaumur for a description of the labours of these.

52. The mother first excavates a cylindrical hole in a horizontal direction eight or ten inches long, either in the ground or in the trunk of a rotten tree, or any other decaying wood. She fills this hole with six or seven thimble-shaped cells, composed of cut leaves, the convex end of each fitting into the open end of the other. Her first process is to form the external coating, which is composed of three or four pieces of larger dimensions than the rest, and of an oval form. The second coating consists of portions of equal size, narrow at one end, but gradually widening towards the other, where the width equals half the length. One side f these pieces is the serrated edge of the leaf from which it was taken, which, as the pieces lap over each other, is kept on the outside, the edge which was cut being within.

The little animal next forms a third coating of similar material,

* Reaumur, vi. 139 to 148.

the middle of which, as the most skilful workman would do in a like case, she places over the margins of those that form the first side, thus covering and strengthening the junctions by the expedient which mechanics call a break-joint. Continuing the same process she gives a fourth and sometimes a fifth coating to her nest, taking care at the closed end or narrow extremity of the cell, to bend the leaves so as to form a convex termination.

After thus completing each cell, she proceeds to fill it to within the twentieth of an inch of the orifice with a rose-coloured sweetmeat made of the pollen collected from thistle blossoms mixed with honey. Upon this she lays her egg, and then closes the orifice with three pieces of leaf, one placed upon the other, concentrical and also so exactly circular in form, that no compasses could describe that geometrical figure with more precision. In their magnitude also they correspond with the walls of the cell with such a degree of precision, that they are retained in their situation merely by the nicety of their adaptation.

The covering of the cell thus adapted to it being concave, corresponds exactly with the convex end of the cell which is to succeed it, and in this manner the little insect prosecutes her maternal labours, until she has constructed all the cells, six or seven in number, necessary to fill the cylindrical hole.

53. The process which one of these bees employs in cutting the pieces of leaf that compose her nest, is worthy of attention. Nothing can be more expeditious, and she is not longer about it than one would be in cutting similar pieces with a pair of scissors. After hovering for some moments over a rose-bush, as it were to reconnoitre the ground, the bee alights upon the leaf which she has selected, usually taking her station upon its edge, so that its margin shall pass between her legs. She then cuts with her mandibles, without intermission, in such a direction as to detach from the leaf a triangular piece. When this hangs by the last fibre, lest its weight should carry her to the ground, she spreads her little wings for flight, and the very moment the connection of the part thus cut off with the leaf is broken, she carries it off in triumph to her nest, the detached portion remaining bent between her legs in a direction perpendicular to her body. Thus, without rule or compass, do these little creatures measure out the material of their work into ovals, or circles, or other pieces of suitable shapes, accurately accommodating the dimensions of the several pieces of these figures to each other. What other architect could carry impressed upon the tablet of his memory such details of the edifice which he has to erect, and destitute of square or plumb-line, cut out his materials in their exact dimensions without making a single mistake or requiring a single subsequent correc-

tion? Yet this is what the little bee invariably does. So far are human art and reason surpassed by that instruction which the insect receives from its Divine Creator.*

54. But of all the varieties of this insect, that of which the architectural and mechanical skill is transcendently the most admirable, is the *hive-bee.* The most profound philosopher, says Kirby, equally with the most incurious of mortals, is filled with astonishment at the view of the interior of a bee-hive. He beholds there a miniature city. He sees regular streets, disposed in parallel directions, and consisting of houses constructed upon the most exact geometrical principles, and of the most symmetrical forms. These buildings are appropriated to various purposes. Some are warehouses in which provisions are stored in enormous quantities. Some are the dwellings of the citizens, and a few of the most spacious and magnificent are royal palaces. He finds that the material of which this city is built, is one which man with all his skill and science cannot fabricate, and that the edifices which it is employed to form are such that the most consummate engineer could not reproduce, much less originate; and yet this wondrous production of art and skill is the result of the labour of a society of insects so minute, that hundreds of thousands of them do not contain as much ponderable matter, as would enter into the composition of the body of a man. *Quel abîme aux yeux du sage qu'une ruche d'abeilles! Quelle sagesse profonde se cache dans cet abîme! Quel philosophe osera le sonder!* Nor has the problem thus solved by the bee, yet been satisfactorily expounded by philosophers. Its mysteries have not yet been fathomed. In all ages naturalists and mathematicians have been engrossed by it, from Aristomachus of Soli and Philiscus the Thracian, already mentioned, to Swammerdam, Reaumur, Hunter, and Huber of modern times. Nevertheless the honey-comb is still a miracle which overwhelms our faculties.†

55. A honey-comb, when examined, is found to be a flattish cake with surfaces sensibly parallel, each surface being reticulated with hexagonal forms of the utmost regularity. No geometrician could describe the regular hexagon with greater precision than is here exhibited.

It is proved in geometry that there are only three regular figures, which, being joined together at their corners, will so fit each other as to leave no unoccupied spaces between them. These figures are the square, the equilateral triangle, and the regular hexagon. Four squares united by one of their angles will fill all

* Reaumur, vi. 971; Kirby, Int., i. 377.
† Kirby, i. 410.

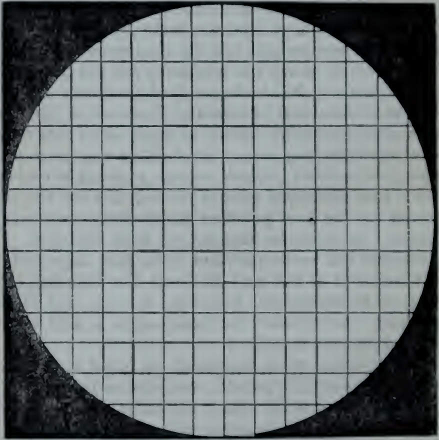
the surrounding space, and any number of squares may thus be combined so as to cover a surface like a mosaic pavement without leaving any intermediate unoccupied spaces.

In like manner six equilateral triangles will have a like property, and in fine, three regular hexagons being similarly united at one of their corners, will in like manner completely occupy the surrounding space.

Since no other regular geometrical figure possesses this property, it follows that a regular mosaic pavement must necessarily be composed of one or other of these figures.

Fig. 19 represents such a pavement composed of squares; and fig. 20, one composed of equilateral triangles; and in fine, fig. 21, one composed of regular hexagons.

Fig. 19.

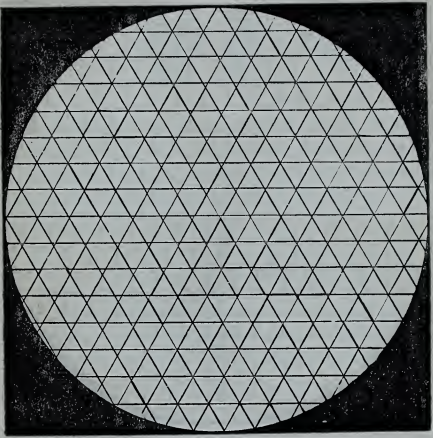


The angles, in fig. 19, are 90°; those in fig. 20, are 60°; and those in fig. 21, 120°. No other angles save these, therefore, could be used in any regular pavement of this kind without leaving intersticial uncovered spaces.

Now it will be at once perceived that the form presented by the surface of a honey-comb is that of an hexagonal pavement. We shall presently see why the bee has selected this in preference to either of the other possible forms.

56. On further examining the comb, it will be found that the hexagonal spaces presented by its surface are the mouths of so

Fig. 20.

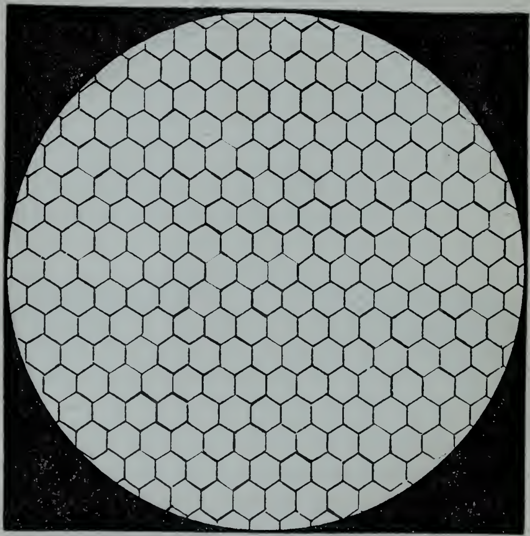


many hexagonal tubes which are filled with honey. If any of these be empty, it will be seen that the depth of these tubes is half the thickness of the comb.

57. It appears therefore that the honey-comb is a combination of hexagonal tubes, placed in juxtaposition, the angles of the hexagon being fitted into each other like the stones of a mosaic pavement; that there are two systems of such tubes, meeting in the middle of the thickness of the comb, their mouths being presented outwards on both sides, and consequently their bases resting against each other.

If by the dissection of the comb, the forms of their bases be examined, they will be found to consist, not as might be at first supposed of plane regular hexagons, which would be the case if they were plane surfaces at right angles to the tube; they will be found, on the other hand, to have the form of pyramids, each of which is composed of three regular lozenges united together at their edges, so as to form an apex; this apex being pointed always towards the opposite side of the comb. The pyramidal base is thus a geometrical figure, having as much regularity as the hexagonal tube, of which it forms the termination, but constructed

Fig. 21.



on a totally different principle. The angles of the lozenges, which form its sides, are one obtuse and the other acute ; and these pyramidal bases of the cells, on one side of the comb, fit into corresponding cavities, made by the similar pyramidal bases of the cells, on the other side of the comb, so as to leave no intermediate unoccupied space.

58. Without the aid of perspective figures, and even with such aid, without some effort of imagination on the part of the reader, it would be impossible to convey a clear notion of this part of the structure of the honey-comb, and yet without such a clear notion it would be totally impossible to appreciate the admirable results of bee industry. We have, therefore, attempted to represent in figs. 22 and 23, the bases of four contiguous cells seen from the inside and from the outside. In fig. 22 is presented an inside view of the bases of three adjacent cells, *a a a*. It must be observed that *a a a* are here intended to represent angular cavities, each formed by the junction of three lozenge-shaped planes, such as have been just described. Now it will be seen, that as a necessary consequence of this juxtaposition, a figure will be formed at *b*, by three lozenge-

shaped planes, one belonging to each of the three bases, *a a a*, and that this, instead of being hollow on the side presented to

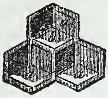
Fig. 22.


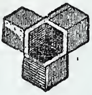
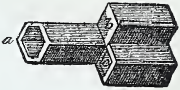
Fig. 23.


Fig. 24.


Fig. 25.


the eye, will be hollow on the opposite side, which is turned from the eye, and will there form an angular cavity precisely similar and equal to the cavities *a a a*, which are turned towards the eye. Now this cavity, which is thus turned to the opposite side, is the base of one of the cells on the other side of the comb. In fig. 23 we have presented a view of the combination as it would be seen on the other side. In this case, the angular cavity darkly shaded in the middle of the figure, is the angular projection, *b*, in fig. 22, seen on the other side; and the three angular projections which surround it, jutting forward towards the eye, are the three angular bases, *a a a*, fig. 22, seen on the other side.

59. A perspective view of a single hexagonal tube or cell, with its pyramidal base, is shown in fig. 24.

The manner in which the hexagonal cells are united base to base to form the comb, is shown in perspective in fig. 25, where *a* is the open mouth of the tube, and *b c* the lozenge-shaped planes, forming the bases of the opposite tubes. The same is shown in section in fig. 26.

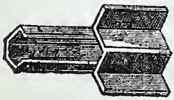
Fig. 26.


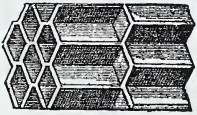
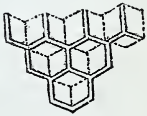
Fig. 27.


Fig. 28.


60. Several hexagonal cells are shown in their natural juxtaposition, placed base to base, as they form the comb, in fig. 27, and a perspective view of their pyramidal bases is given in fig. 28.

Nothing can be more surprising than this production of such an insect, when regarded as a piece of scientific engineering. The substance which comprises it being one secreted by the bees in limited quantity, it was of the greatest importance in its use, that a material so scarce should be applied so as to produce the greatest possible result, with the smallest possible quantity of the material. The problem, therefore, which the bee had to solve was, with a given quantity of wax, to construct a combination of similar and equal cells of the greatest aggregate capacity, and such as to occupy the available space in the hive to the greatest possible advantage. The form and magnitude of the cells must necessarily have been adapted to those of the bee itself, because these cells are intended to be the nests in which the eggs are laid and hatched, and the young bee raised to its state of maturity.

The body of the bee being oblong, and measuring about six-tenths of an inch in length by two-tenths in diameter, cylindrical tubes of corresponding dimensions would have answered the purpose; but such tubes could not be united together in juxtaposition without either a great waste of wax or great deficiency of strength, since, when placed in contiguity, they would leave between them empty spaces of considerable magnitude, which, if left unoccupied, would render the structure weak, and if filled with wax, would have the double disadvantage of giving needless and injurious weight to the comb, and involving the waste of a quantity of a scarce and precious material, greater than all that would be necessary to form the really useful part of the comb.

61. From what has been explained it will be understood that, to form a combination of tubular cells without interstices, the choice of the bee was necessarily limited to the three figures already mentioned—the equilateral triangle, the square, and the regular hexagon. The equilateral triangle would be attended with the disadvantage of a great waste of both space and material; for if its dimensions were sufficient to afford easy room to the body of the bee, a large space would be wasted at each of the angles, towards which the body of the bee could never approach.

A like disadvantage, though less in degree, would have attended square tubes. The bee, therefore, with the instinct of an engineer, decided on the third form, of the regular hexagon, which at once fulfilled the conditions of a sufficiently near adaptation to the form of its own body, and the advantage of such a combination as would leave neither waste space nor loss of material.

62. In the structure of the comb there is still another point worthy of attention. It might naturally have been expected that it would be composed of a single layer of cells, one side presenting the mouth, and the other the pyramidal base; but if this had been the course adopted, the side consisting of the pyramidal bases would be an extensive surface, upon which the industry of the bee would have no occupation, and the space in the hive to which such surface would be presented would, therefore, be so much space wasted. Instead, therefore, of constructing the comb of a single layer of cells, the bees judiciously make it of a

double layer, the pyramidal bases of each layer being placed in contact with each other.

It might also have been expected that these bases would have received the most simple form of plane surfaces, so that the side of each layer occupied by them would be a uniform plane; and these planes resting in contact would form the comb; but to this there would be several objections. In the first place, the capacity of the comb would be less; the bases of the cells, placed in contact, would be liable to slip one upon the other; and if the cells had a common base, they would have less strength; but independently of this, the bee itself tapers towards its posterior extremity, and a cell with a flat bottom having no corresponding tapering form would be little adapted to its shape, and would involve a consequent waste of space. The bee avoids this disadvantage by giving the bottom of the cell the shape of a hollow angular pyramid, into the depth of which the tapering posterior extremity of the insect enters.

63. There is another advantage in this arrangement which must not be overlooked. The pyramidal bases of each layer of cells, placed in juxtaposition by reciprocally fitting each other, so that the angular projections of each are received into the angular cavities of the other, are effective means of resisting all lateral displacement.

64. Pyramidal bases, however, might have been given to the cells in a great variety of ways, which would have equally served the purposes here indicated; but it was essential, on grounds of economy, that that form should be selected which would give the greatest possible capacity with the least possible material. On examining curiously the form of the lozenges composing the pyramidal bases of the cells, Maraldi found by accurate measurement that their acute angle measured 70° 32′, and consequently their obtuse angle 109° 28′. Magnitudes so singular as these, invariably reproduced in all the regular cells, could scarcely be imagined to have been adopted by these little engineers without a special purpose, and Reaumur accordingly conjectured that the object must have been the economy of wax.

Not being himself a mathematician sufficiently profound to solve a problem of this order, he submitted to M. Koenig, an eminent geometer of that day, the general problem to determine the form which ought to be given to the pyramidal bottom of an hexagonal prism, such as those constituting the cones, so that with a given capacity, the least possible material would be necessary for the construction. The problem was one requiring for its solution the highest resources to which analytical science had then attained. Its solution, however, was obtained, from which it appeared that the proper angles for the lozenges would be 70° 34′ for the acute, and consequently 109° 26′ for the obtuse angle. Here are then in juxtaposition the result of the labours of the geometer and the bee.

	ACUTE ANGLE.	OBTUSE ANGLE.
Geometer	70° 34′	109° 26′
Bee	70° 32′	109° 28′

We leave the reader to enjoy the contemplation of these numbers without one word more of comment.

65. "Besides the saving of wax effected by the form of the cells, the bees adopt another economical plan suited to the same end. They compose the bottoms and sides of wax of very great tenuity, not thicker than a sheet of writing-paper ; but as walls of this thickness at the entrance would be perpetually injured by the ingress and egress of the workers, they prudently make the margin at the opening of each cell three or four times thicker than the walls. Dr. Barclay discovered that though of such excessive tenuity, the sides and bottom of each cell are actually double, or in other words, that each cell is distinct, separate, and in some measure an independent structure, agglutinated only to the neighbouring cells; and that when the agglutinating substance is destroyed, each cell may be entirely separated from the rest. This, however, has been denied by Mr. Waterhouse, and seems inconsistent with the account given by Huber, hereafter detailed; but Mr. G. Newport asserts, that even the virgin-cells are lined with a delicate membrane." *

* Kirby, i. p. 412.

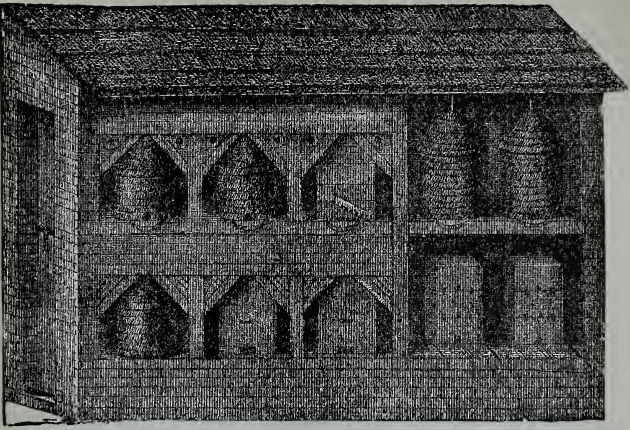


Fig. 55.—COVERED APIARY.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER III.

66. Drone cells and worker cells.—67. Store cells.—68. Construction of combs.—69. Wax-makers also produce honey.—70. First operation of the wax-makers.—71. Process of the foundress.—72. Kneading the wax.—73. Formation of first wall.—74. Correction of mistakes.—75. Dimensions of first wall.—76. Operations of the nurses.—77. Bases of cells.—78. Wax-makers resume their work.—Completion of pyramidal bases.—79. Pyramidal partition.—80. Formation of cells.—81-82. Arrangement of combs.—83. Sides not parallel.—84. Process not merely mechanical.—85-86. Process of construction.—87. Labour successive.—88. Dimensions of cells.—89. Their number.—90. Bee-bread.—91. Pap for young.—92. Food adapted to age.—93. Transformation.—94. Humble-bees—females.—95. Their nursing workers.—96. Transformation.—97. How the temperature of the cocoons is maintained.—98. Anecdote related by Huber.—99. Remarkable care of the nurses.—100. Heat evolved in respiration by the hive-bee.—101. Cross alleys connecting the streets.—102. First laying of the queen in Spring.—103. Her royal suite.—104. The eggs.

66. Since the population of the hive is composed, as already explained, of different classes of individuals having different stature, and since one of the purposes of the cells is to be their

abode from the time they issue from the egg until they attain maturity, it follows that the capacity of the cells, or such of them as are thus appropriated, must be subject to a corresponding difference. The cells of the workers will therefore be less in magnitude than those of the drones, and these last much less than the royal cells. The comb therefore consists of different parts reticulated by hexagons of different magnitudes, the smaller ones being the mouths of the cells appropriated to the workers, and the larger those of the cradles of the drones. As to the royal cells they differ altogether from the others, not only in capacity, but also in position and form. As already explained, the general forms of the cells are hexagonal tubes, with pyramidal bases, and open mouths ranged horizontally, their axes being at right angles to the flat sides of the comb. The comb itself is placed vertically in the hive, and the royal cells which are large and pear-shaped are cemented to its lower edges, hanging from it vertically like stalactites from the roof of a cavern. Although there be but one queen in each hive, she produces, nevertheless, three or four or more, and sometimes even as many as thirty or forty royal eggs. The princesses which issue from these, are destined to be the queens of the successive swarms which the hive sends forth.

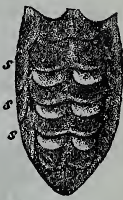
67. The cells which are appropriated exclusively to the storage of honey and pollen, are similar in form and position to those appropriated to the young drones and workers, but are greater in length, and this length the bees vary according to the exigencies of their store of provisions. If more of these result from their labours than the cells constructed can contain, and there is not time or space for the construction of more cells, they lengthen the honey-cells already made by cementing a rim upon them. They sometimes also use for storage, cells which have already been occupied by young drones or workers, which, having attained their state of maturity, have vacated them.

68. Having thus explained in general the forms and structures of the cells, we shall briefly explain the operation by which the bees construct them, and by their combination form the combs.

The material of the combs is *wax*, a substance secreted beneath the ventral segments of the bodies of that class of the workers which, from this circumstance, has received the name of wax-makers. The apparatus by which the material which ultimately acquires the character of wax is secreted, consists of four pairs of membranous bags, called wax-pockets, which are situated at the base of each segment of the body, one on each side, and which in the natural condition of the body, are concealed by the segments overlapping each other. They can, however, be rendered visible by drawing out the body longitudinally, so that the part of each segment covered by the preceding one shall be disclosed (fig. 29).

In these pockets the substance to be ultimately converted into wax is secreted from the food taken into the stomach, which, transpiring from thence through the membrane of the wax-pocket, is formed there in thin laminæ. The stomach and its appendages which are endowed with these functions, though much less capacious in the nurses than in the wax-makers, is not altogether absent; and the nurses have a certain limited power of secreting wax. In them the wax-making function, however, seems to exist in little more than a rudimentary state.

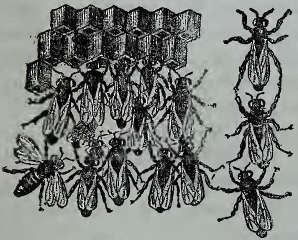
Fig. 29.



69. Although the chief duty of the wax-makers is that from which they have taken their names, they are also capable of producing honey, and when the hive is abundantly furnished with combs, they accordingly change the object of their industry and produce honey instead of wax.

70. When a comb is about to be constructed, the operation is commenced by the wax-makers, who, having taken a due portion of honey or sugar, from either of which wax can be elaborated, suspend themselves one to another—the claws of the fore-legs of the lowermost being attached to those of the hind-legs of the next above them, so that they form a cluster, the external surface of which presents the appearance of a fringed curtain (fig. 30). After having remained in this state unmoved for about twenty-four hours, during which period the material of the wax is secreted, the thin laminæ into which it is formed may generally be perceived under the abdomen.

Fig. 30.



A single bee is now seen to separate itself from the cluster and to pass from among its companions to the roof of the hive, where by turning itself round, it clears a circular space for its work, about an inch in diameter. Having done this, it proceeds to lay the foundation of a comb in the following manner, if one may be permitted to apply the word foundation to the top of a suspended structure.

71. The foundress bee, as this individual is called, commences its work by seizing with one of its hind feet a plate of wax, or rather of the material out of which wax is to be constituted, from between the segments of its abdomen. The insect is

represented in this act in fig. 31. Having fixed a secure hold on the lamina, it carries it by its feet from the abdomen to its mouth, where it is taken by one of the fore-legs which holds it vertically while the tongue rolled up serves for a support, and by raising and depressing at will, causes the whole circumference to be brought successively under the action of the mandibles (fig. 32), so that the margin is soon ground into pieces. These pieces fall gradually as they are detached in the double cavity of the mandibles which are bordered with hair.

Fig. 31.

Fig. 32.

The mandibles or jaws which execute this process open in a horizontal, instead of a vertical, direction as in the case of the superior animals, and have a form resembling that of a pair of shears or scissors.

72. The fragments of the laminæ thus divided falling on either side of the mouth, and pressed together into a compact mass, issue from it in the form of a very narrow ribbon. This ribbon is then presented to the tongue by which it is impregnated with a frothy liquor, which has the same effect upon it as water has on potter's earth in the formation of porcelain paste. That this process, by which the raw material of the wax is worked and kneaded, is an extremely elaborate and artificial one, is rendered apparent by observing carefully the manœuvres of the bee's tongue in the process. Sometimes that organ assumes the form of a spatula, or apothecary's knife, sometimes it takes the form of a mason's trowel, and sometimes that of a pencil tapering to a point, never ceasing to work upon the ribbon which is being evolved from the mouth in these several forms.

After the ribbon has been thus thoroughly impregnated with moisture, and carefully kneaded, the tongue again pushes it between the mandibles, but in a contrary direction to that in which it previously passed, when the whole is worked up anew.

The substance is now converted into true wax, the characteristic properties of which it has acquired in this process. The material evolved in laminæ from the segments of the abdomen is brittle and friable, and would be as unfit for the structure of the comb as dry potter's earth would be for the formation of a vase. The liquid secreted from the mouth, with which it has been impregnated, and the elaborate process of kneading which it has undergone, have totally changed its mechanical properties and have imparted to it that ductility and plasticity so eminently characteristic of wax. It has also undergone other physical changes. The laminæ taken from the abdominal segments are colourless and transparent, the substance into which they are converted being white and opaque.

73. The pieces of wax thus elaborated the insect applies against the roof of the hive, arranging them with her mandibles in the intended direction of the comb. She continues thus until she has in this way applied the wax produced from the entire laminæ, when she takes in like manner another from her abdomen, treating it in the same way. After thus heaping together all the wax which her organs have secreted, and causing it to adhere by its proper tenacity to the vaults of the hive, she withdraws from her work and is succeeded by another labourer who continues the same operations, who is followed in a like manner by a third and fourth, and so on, all disposing the produce of their labour in the direction first intended to be given to the comb.

74. Nevertheless it would seem that the curious facility by which these proceedings are directed is not altogether unerring, for it happens by chance now and then that one of the workers will commit a mistake by placing the wax in the wrong direction. In such cases, the worker which succeeds never fails to rectify the error, removing the materials which are wrongly placed, and disposing them in the proper direction.

75. The result of all these operations of the wax-makers is the construction of a rough wall of wax about half an inch long, a sixth of an inch high, and the twenty-fourth of an inch thick, which hangs vertically from the roof of the hive. In the first rough work there is no angle nor the least indication of the form of the cells. It is a mere straight and plain vertical partition of wax, roughly made, about the twenty-fourth of an inch thick, and such as can only be regarded as the foundation of a comb.

76. The duty of the *wax-makers* terminating here, they are succeeded by the *nurses*, who are the genuine artisans; standing in relation to the wax-makers in the same manner as, in the construction of a building, the masons who work up the materials into the form of the intended structure would to the common labourers. One of the nurses commences its operation by placing itself horizontally on the roof of the hive, with its head presented to the wall of wax constructed by the wax-makers. This wall or partition is intended to be converted into the system of pyramidal bases of the cells already described, and accordingly the first

labour of the nurses is directed to accomplish this change. Their first operation, therefore, is to mould on that side of the wall to which its head is directed, a pyramidal cavity having the form of the base of one of the intended cells. When it has laboured for some minutes thus, it departs and is succeeded by another, who continues the work, deepening the cavity and increasing its lateral margins by heaping up the wax on either side by means of its teeth and fore-feet, so as to give the sides a more regular form. More than twenty nurses succeed each other in this operation.

77. It must be remembered that during this process, nothing has been done on the other side of the partition, but when the cell just described has attained a certain length, other nurses approach the opposite side of the partition and commence the formation of the pyramidal base of two cells corresponding in position with that just described, and these in like manner prosecute their labours, constantly relieving each other.

78. While the nurses are thus employed in converting the rough partition into the pyramidal bases of cells, and in forming the hexagonal tubes corresponding to these pyramidal bases, the wax-makers return and, resuming their labour, increase the magnitude of the partition in every direction, the nurses meanwhile still prosecuting their operations.

After having worked the pyramidal bases of the cells of one row into their proper forms, they polish them and give them a high finish, while others are engaged in laying out the next series.

79. In fig. 33, is represented one of the faces of such a partition

Fig. 33.

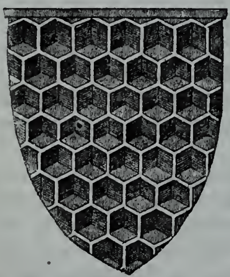
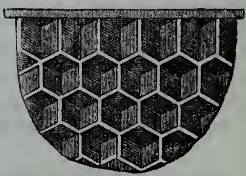


Fig. 34.



as is here described, after it has been formed into a continuous system of pyramidal bases. These are intended to represent the bases of the cells of the workers. A similar piece showing the bases of the cells of the drones is represented in fig. 34.

80. The cells themselves, consisting, as already explained, of

hexagonal prismatic tubes, are the next objects of the industry and skill of the nurses. These are cemented on the borders of the pyramidal cavities shown in figs. 26 and 27.

81. The surfaces represented in figs. 33 and 34 having a contour very unequal, the edges of the pyramidal cavities being inclined to each other, so as to form angles alternately salient and re-entrant, the first work of the bees is to form those parts of the prismatic sides of the cells which are necessary to fill up the re-entrant angles of the contours of the pyramidal bases. When this has been accomplished, the contours of all the hexagonal divisions extended over the surface of the partition, represented in figs. 33 and 34, are brought to a common level, and from that point the labour of the little artificers becomes more simple, consisting of the construction of the oblong rectangles which form the remainder of the six sides of each cell.

82. It must nevertheless be remarked, that the first row of cells, being necessarily attached to the roof of the hive, and not at its upper edge connected like the other rows with other similar cells, has an exceptional form, these being not hexagonal, but pentagonal; two of the sides of the ordinary cells being replaced by the roof of the hive, as shown in figs. 33 and 34. A corresponding exceptional form is of course also given to the bases of the first row of cells.

The combs constructed in this manner are ranged in vertical planes parallel one to the other in the hive, as shown in perspective in fig. 35, in vertical section in fig. 36, and in horizontal

Fig. 35.

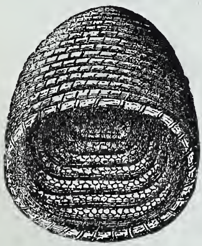
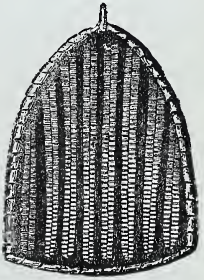


Fig. 36.



section in fig. 37. They are not always ranged strictly in single parallel lines; but are sometimes bent at an angle, as shown in fig. 37.

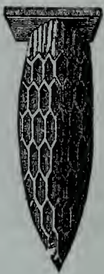
An end view of a comb, showing the mouths of the cells foreshadowed by perspective, is represented in fig. 38.

83. The flat sides of a comb are not strictly parallel, but

generally slightly inclined one to the other, so that the thickness gradually diminishes from top to bottom, as shown in the vertical section, fig. 36. This gradation of thickness is continued to a

Fig. 37.

Fig 38.



certain point, while the width of the comb is continually augmented; but so soon as the workers obtain sufficient space to lengthen it, it begins to lose this form, and the surfaces become sensibly parallel.

84. A certain class of naturalists, who have directed their attention to the history of this insect, appear to have taken a pleasure in forming hypotheses, by which it would be reduced to a mere machine. Thus, according to them, the formation of the various parts of the comb would result from a mere mechanical necessity, the organs of the insect being supposed to be so formed that the different parts of the cells would receive their forms by a mechanical process, as in certain operations in the arts the most exact geometrical forms are imparted to materials by punches and dies expressly made for the purpose.

Between such expedients and the organs of this admirable insect, there is, however, not the remotest analogy.

The mechanical instruments with which they work are the feet, the mandibles, and the tongue, the operations of which are guided by the antennæ, which are feelers of exquisite sensibility. They do not remove in their operations a single particle of wax, until the surface to be sculptured has been carefully explored by the antennæ. These organs are so flexible and so easily applied to all parts, however delicate, of their workmanship, that they are capable of performing the offices of square and compass, measuring the minutest parts with the utmost precision, so as to guide the work in the dark, and produce with unerring precision that wondrous structure called the comb.

85. It is impossible to behold a dissected comb without perceiving the geometrical necessity which connects one part with

another. In the formation of such a structure, chance can have no share. The original mass of wax is augmented by the labour of the wax-makers in the exact quantity which is necessary; and these wax-makers, who thus are constantly on the watch to observe the progress of the comb, so as to keep the artificer-bees constantly supplied with the necessary quantity of raw material, are themselves utterly destitute of the art and science necessary to construct the cells.

86. The bees never commence the construction of two contiguous and parallel combs together, for the obvious reason, as it should seem, that to make one parallel to and at a given distance from another, the actual formation of one must be first accomplished to a certain point. They therefore begin by the middle comb; and when that has been constructed to a certain depth, measured from the top of the hive, two other combs, parallel to it and at regulated distances from it at either side, are commenced; and when these again are completed to a certain depth, two others outside these are commenced, and so on. This order of proceeding is attended with a further advantage by preventing the workers on one comb from being inconveniently crowded or obtruded upon by those of the adjacent combs.

87. The labour of the bees is conducted in common, but not always simultaneously. Every partial operation is commenced by one individual bee, who is succeeded in her labours by others, each appearing to act individually in a direction depending on the condition in which she finds the work when it falls into her hands. The whole band of wax-makers, for example, is in complete inaction until one of them goes forth to lay the foundation of a comb. Immediately the labours of this one are succeeded and seconded by the others, and, when their part is done, an individual nurse-bee goes to lay out the plan of the first cell, and is in like manner succeeded continuously by others.

88. "The diameter of the cells intended for the larvæ of the workers is alway $2\frac{2}{5}$ lines, and that of those meant for the larvæ of the males or drones $3\frac{1}{3}$ lines. The male-cells are generally in the middle of the combs, or in their sides; rarely in their upper part. They are never insulated, but form a corresponding group on both sides the comb. When the bees form male-cells below those of neuters, they construct many rows of *intermediate* ones, the diameter of which augments progressively till it attains that of a male-cell; and they observe the same method when they revert from the male-cells to those of workers. It appears to be the disposition of the *queen* which decides the kind of cells that are to be made; while she lays the eggs of workers, no male-cells are constructed; but when she is about to

lay the eggs of males, the workers appear to know it, and act accordingly. When there is a very large harvest of honey, the bees increase the diameter and even the length of their cells. At this time many irregular combs may be seen with cells of twelve, fifteen, and even eighteen lines in length. Sometimes, also, they have occasion to shorten the cells. When they wish to lengthen an old comb, the sides of which have acquired their full dimensions, they gradually diminish the thickness of its edges, gnawing down the sides of the cells till it assumes the lenticular form; they then engraft a mass of wax round it, and so proceed with new cells." *

89. The number of cells contained in the combs of a well-stocked hive is considerable. In a hive twenty inches high and fourteen inches diameter, they often amount to forty or fifty thousand. A piece of comb, measuring fourteen inches long and seven inches wide, containing about 4000 cells, is frequently constructed in twenty-four hours.

90. Nothing can be more admirable than the tender solicitude and foresight shown by the bee towards its offspring. Although these insects provide a great number of cells, as storehouses, for the honey intended for the use of the community, yet the object which more exclusively engrosses them is the care of their young, to the provision and rearing of which they sacrifice all personal and selfish considerations. In a new swarm, accordingly, the first care of these insects is to construct cradles for their young, and the next, to provide an ample store of a peculiar sort of *pap*, called *bee-bread*, for their food.

This bee-bread consists of the pollen of flowers, which the workers at this time are incessantly employed in gathering, flying from flower to flower, brushing from the stamens their yellow treasure, which they collect in the little baskets with which their hind-legs are so admirably provided. They then hasten back to the hive, where, having deposited the store thus collected, they return to seek a new load.

Another troop of labourers are in constant attendance in the hive to receive the stock of bee-bread thus collected, which they carefully store up until such time as the queen has laid her eggs. These eggs she places in an upright position in the bottoms of the cells, where they are severally hatched.

91. The bee-bread is converted into a sort of pap, or whitish jelly, by being swallowed by the bee, in the stomach of which it is probably mixed with honey and then regurgitated.

The moment the young brood issue from the eggs in the state of larvæ, they are diligently fed with this jelly by the class of bees

* Kirby, i. 419.

called nurses, who attend them with all the solicitude implied by their title, renewing the pap several times a day, as fast as it is consumed.

The curious observer will see, from time to time, different nurses introduce their heads into the cells containing the young. If they see that the stock of pap is not exhausted, they immediately withdraw and pass on to other cells; but if they find, on the contrary, the provision consumed, they never fail to deposit a fresh supply. These nurses go their rounds all day long in rapid succession thus surveying the cradles, and never stopping except where they find the supply of food nearly exhausted.

92. That the duty of these tender nurses is one which requires the exertion of some skill will be understood, when it is stated that the quality of food suitable to the young varies with their age. When they first emerge from the egg the jelly must be thin and insipid, and, according as they approach to maturity, it requires to be more strongly impregnated with the saccharine and acid principles.

Not only does the food of the larva thus require to be varied according to its age, but the food to be supplied to different larvæ is altogether different. The jelly destined for the larvæ which are to become queens, is totally different from that prepared for those of drones and workers, being easily distinguished by its sharp and pungent flavour; and it is probable, also, that the jelly appropriated to the drones differs from that upon which the workers are reared.

These insects, moreover, exhibit as much economy as skill; the quantity of food provided being as accurately proportioned to the wants of the young as its quality is to their varying functions. So accurately is the supply proportioned to the wants of the larvæ, that, when they have attained their full growth and are about to undergo their final metamorphosis into nymphs, not an atom of bee-bread is left unconsumed.

93. At the epoch of this metamorphosis, when the nymph needs seclusion to spin its cocoon, and has no further occasion for food, these tender nurses, with admirable foresight, terminate their cares by sealing up each cell, enclosing the nymph with a woven lid.

In all the maternal cares described above, neither the drones nor the queen participate. These duties fall exclusively upon the workers, and are divided between them, as has been explained, the task of collecting the bee-bread being appropriated to one set, and that of feeding and tending the young to another. This duty has no cessation; as the queen lays her eggs successively and constantly, the young arrive successively at the epoch of their first metamorphosis; and, consequently, so soon as some are sealed up and abandoned by the nurses to spin their cocoons, others issue from the egg and demand the same maternal care; so that these nurses spend their whole existence in the discharge of the offices here described.

94. Although the organisation of other species of the bee does not approach to the perfection of the hive-bee here described, it is nevertheless worthy of attention and study.

The humble-bees, which so far as respects their social policy, compared with the hive-bee, may be regarded as rude and uncivilised rustics, exhibit nevertheless marks of affection for their young quite as strong as their more polished neighbours.

Unlike the queen of the hive, the females take a considerable share in the education of the young. When one of these provident mothers has constructed with great labour and much skill a commodious woven cell, she furnishes it with a store of pollen moistened with honey, and, having deposited six or seven eggs in it, carefully closes the opening and all the interstices with wax; but her maternal cares do not end here. By a strange instinct, probably necessary to restrain an undue increase of the population, the workers, while she is laying her eggs, endeavour to seize them, and, if they succeed, greedily devour them. Her utmost vigilance and activity are scarcely sufficient to save them; and it is only after she has again and again repelled the murderous intruders, and pursued them to the furthest verge of the nest, that she succeeds in accomplishing her object; and even when she has sealed up the cell containing them, she is obliged to continue to guard it for six or eight hours; since otherwise the gluttonous workers would break it open and devour the eggs. The mother is conscious, however, by a heaven-inspired knowledge, of the time when the eggs will cease to excite the appetites of the depredators.

After this the cells remain unmolested until the larva issues from the eggs. The maternal cares having there ceased, the workers, before so eager to devour the eggs, now assume the character of nurses. They know the precise hour when the larvæ will have consumed the stock of food, provided for them by maternal care, and from that time to the period of their maturity these nurses continually feed them with honey or pollen, introduced in their proboscis through a small hole in the cover of the cell opened for the purpose, and then carefully closed.

95. These nursing-workers also perform another duty of a most curious and interesting description. As the larva increases in size, the cell, which has been appropriated to it, becomes too small for its body, and in its exertions to obtain room it splits the thin woven walls which confine it. The workers, who are constantly on the watch for this, lose no time in repairing the breach, which

they patch up with wax as often as the fracture takes place, so that in this way the cell increases in size until the larva arrives at maturity.

96. As in the case of the hive-bee already described, the larva after the first metamorphosis, is shut up in the enlarged cell to spin its cocoon. When this labour has been completed, and that the perfect insect is about to issue, the workers still discharging the duty of tender foster-parents, set about to assist the little prisoner in cutting open the cocoon, from which it emerges in its perfect state.

97. While in the pupa state, however, another tender and considerate measure of the workers must not be passed without notice. It is essential to the well-being of the pupa that while concealed in the cocoon it should be maintained at a genial temperature. To secure this object, the workers collect upon the cocoons in cold weather and at night, so that by brooding over them they may impart the necessary warmth.

98. The following curious anecdote connected with this subject is related by Huber.

"He put under a bell-glass about a dozen humble-bees, without any store of wax, along with a comb of about ten silken cocoons, so unequal in height that it was impossible the mass should stand firmly. Its unsteadiness disquieted the humble-bees extremely. Their affection for their young led them to mount upon the cocoons for the sake of imparting warmth to the enclosed little ones, but in attempting this the comb tottered so violently that the scheme was almost impracticable. To remedy this inconvenience, and to make the comb steady, they had recourse to a most ingenious expedient. Two or three bees got upon the comb, stretched themselves over its edge, and with their heads downwards fixed their fore-feet on the table upon which it stood, whilst with their hind-feet they kept it from falling. In this constrained and painful posture, fresh bees relieving their comrades when weary, did these affectionate little insects support the comb for nearly three days. At the end of this period they had prepared a sufficiency of wax, with which they built pillars that kept it in a firm position: but by some accident afterwards, these got displaced, when they had again recourse to their former manœuvre for supplying their place; and this operation they perseveringly continued, until M. Huber, pitying their hard task, relieved them by fixing the object of their attention firmly on the table." *

It is impossible not to be struck with the reflection, that this most singular fact is inexplicable on the supposition, that insects are impelled to their operations by a blind instinct alone. How

* Linnæan Trans., vi. 247, *et seq.*

could mere machines have thus provided for a case which in a state of nature has probably never occurred to ten nests of humble-bees since the creation? If in this instance these little animals were not guided by a process of reasoning, what is the distinction between reason and instinct? How could the most profound architect have better adapted the means to the end—how more dexterously *shored* up a tottering edifice, until his beams and his props were in readiness? *

99. The following remarkable example of the care bestowed by the nurses in keeping the pupa warm, more especially during the day which immediately precedes its exit from the cocoon as a perfect insect—an epoch, when as it would seem it is more especially necessary that it should be maintained at an elevated temperature,—was supplied by Mr. Newport. That naturalist observed that in the process of incubation, the humble-bee at that particular stage increased considerably the force of its respiration. To render the purpose of this intelligible to the reader not accustomed to physiological enquiries, it may be necessary to state that in the act of respiration the oxygen, which is one of the constituents of the atmosphere, enters into combination with the carbon and hydrogen, which compose part of the body of the animal. Now this combination being identical with that which produces heat in a common coal fire or the flame of a lamp, the same effect is produced in the animal economy from the same cause; and hence it arises that the development of heat in the body is always so much the greater, in proportion to the increased activity of respiration.

100. To return to the hive-bee, it was observed by Mr. Newport that in the early stage of the incubation of the pupa, the rate of respiration of the insect is very gradual, but becomes more and more frequent as the epoch approaches at which it issues from the cocoon; the number of respirations per minute then amounting to 120 or 130.

Mr. Newport states that he has seen a bee upon the combs continue perseveringly to respire at that rate for eight or ten hours, until its temperature was greatly increased and its body bathed in perspiration. When exhausted in this way it would retire from its maternal duty and give place to another foster-mother, who would proceed in the same way to impart warmth to the pupa.

In one case Mr. Newport found that while the thermometer in the external air stood at 70·2, it rose on the lips of these cells which were not brooded upon at the moment, to 80·2, but when placed in contact with the bodies of the brooding bees, it rose

* Kirby, Int., i. 320.

to 92·5. It appears therefore that by the voluntary increase of their respiration they were enabled to impart to the nymph enclosed in the cocoon 12·3 additional degrees of heat.*

101. In every well-filled hive the combs are ranged in parallel planes, as shown in figs. 36, 37; and that no space may be lost, while at the same time sufficient room is left for the movements of the workers, the open spaces between the parallel combs leave a width just sufficient to allow two bees easily to pass each other. These open spaces are the streets of the apiarian city, the highways along which the building materials are carried while the combs are in process of construction, through which the supply of provisions is carried to the stores, and food to the young, who are being reared in the cells.

But since the nurses must tend the cells of all the combs, and therefore pass successively and frequently from street to street, they would be compelled to descend to the lower edge of the comb to arrive at an adjacent street, unless cross alleys were provided at convenient points to abridge such journeys. The prudent architects foresee this in laying out their city, and make such passages, alleys, or arcades, by which the bees can pass from any street to the adjacent parallel street, without going the long way round.

102. On the return of spring, when the genial temperature of the weather begins to produce its wonted effects on vegetation, and when the vernal plants which the bees love begin to put forth their foliage and flower, the busy population of the hive recommence their labours; and the queen, who has passed the winter in repose, attended by her devoted subjects, and feeding on the stores laid up by them during the previous season, commences laying her great brood of eggs. At this epoch she is much larger than at the cessation of her laying in the autumn. Before she deposits an egg, she examines carefully the cell destined for it, putting her head and shoulders into it, and remaining there for some time, as if to assure herself that the cradle of her offspring has been put in proper order. Having satisfied herself of this, she withdraws her head, and introducing the posterior extremity of her abdomen deposits a single egg upon the pyramidal base of the cell, which adheres there in the manner already described.

She then passes to another empty cell, where, after the same precautions, she deposits another egg, and so continues, sometimes committing to the cells two hundred eggs and upwards in the day.

103. In this operation, so essential to the maintenance of the population, she is assiduously followed and most respectfully

* Philosophical Trans., 1837, p. 296.

surrounded by a certain train of her subjects, appointed apparently to attend her, and form the ladies-in-waiting on the occasion. They range themselves in a circle around her (fig. 39). From time to time

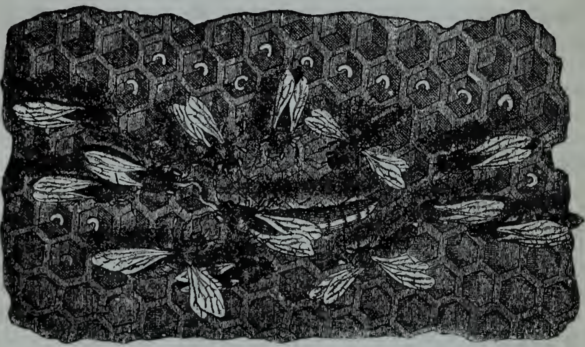


Fig. 39.—The queen depositing her eggs in the cells, surrounded by her suite.

the individuals of her suite approach her and present her with honey. They enter the cells where the eggs have been deposited, and carefully clean them, and prepare them for the reception of the pap which is to feed the young when it issues from the egg.

104. In some exceptional cases, where her majesty is rendered over prolific by any accidental cause, the eggs will drop from her faster than she can pass from cell to cell, and in such cases two or more eggs will be deposited in the same cell. Since the cells are constructed only of sufficient magnitude for the due accommodation of a single bee, the royal attendants in such cases always take away the supernumerary eggs, which they devour, leaving no more than one in each cell (fig. 40).

The eggs are oval and oblong, about the twelfth of an inch in length, of a bluish white colour, and a little bent. They are hatched by the natural warmth of the hive (from 76° to 96° Fahr.), in from three to six days, the interval depending on the temperature of the weather.

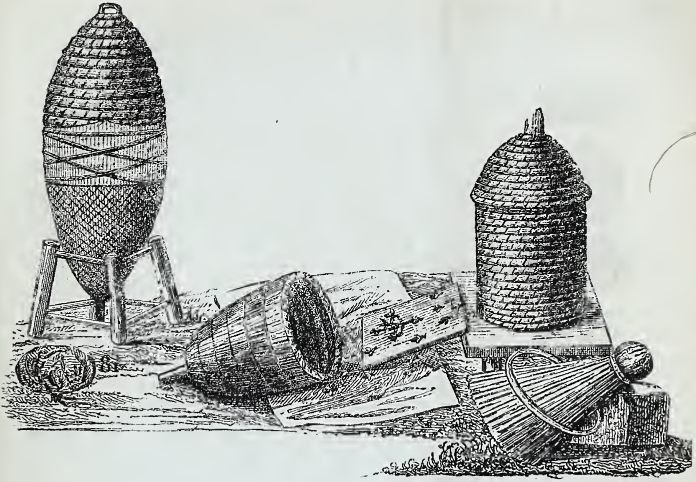


Fig. 58.—VILLAGE HIVES.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER IV.

105. The larvæ.—106. Transformation of worker nymph.—107. Worker cells.—108. Treatment of a young worker.—109. Of the drone.—110. Drone nymph.—111. Royal cell and nymph.—112. Its treatment.—113. Honey cells.—114. Pasturage—progress of work.—115. Construction of comb.—116. Remarkable organisation.—117. Magnitude and weight of bees.—118. Character of queen.—119. Royal jealousy.—120. Principle of primogeniture.—121. Assassination of rivals.—122. Battle of virgin queens.—123. Reason of mutual hostility.—124. Result of the battles.—125. Battle of married queens.—126. Battle of a virgin with a fertile queen.—127. Sentinels at the gates. Treatment of an intruding queen.—128. Remarkable proceeding of bees that have lost their queen—effect of her restoration.—129. Effect of the introduction of a new queen.—130. Policy of the hive.—131. Operations at the beginning of a season.

105. The larva which issues from the egg is a white grub, destitute of legs, having its body divided transversely by a series of parallel circular grooves into annular segments. When it has

grown so as to touch the opposite angle of the cell, it coils itself up in the form of a circular arc, or as Swammerdam describes it, like a dog going to sleep. It floats there in a whitish transparent fluid, provided for it by the nurses, on which it probably feeds during this early stage of its life. Its dimensions are gradually enlarged until its extremities touch one another, so as to form a complete ring, fig. 41, in the base of the cell. In this state the grub is fed with the pap or bee bread already mentioned. The slightest movement on the part of the nursing bees is sufficient to attract its attention, and it eagerly opens its little jaws to receive the offered nourishment, the supply of which, presented by the nurse, is liberal without being profuse.

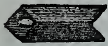


Fig. 40.

Fig. 41.

Fig. 42.

Fig. 43.

The growth of the larva is completed in from four to six days, according to the temperature of the weather. In cool weather the development takes two days more than in warm weather.

When it has attained its full growth, it occupies the whole breadth and a great part of the length of the cell. The nurses at this time knowing that the moment has arrived at which the first metamorphosis, in which the grub is changed into a nymph, takes place, discontinue the supply of food, and close up the mouth of the cell by a light brown waxen cover, which is convex externally. This convexity of the cover is greater in the drone cells than in those of the workers. The covers of the honey cells are, on the contrary, made paler in colour, and quite flat or even a little concave externally.

Fig. 44.

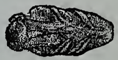
When the larva has been thus enclosed, it immediately commences, like the silk-worm, to spin a cocoon. In this labour it is incessantly employed, lining the sides of its cell and encasing its own body in a white silken robe. The threads which form this mantle issue from the middle of the under lip of the nymph, as the insect in this intermediate state between that of the grub and the perfect bee is called. This thread consists of two filaments, which, issuing from two adjoining orifices in the spinner, are then gummed together.

106. The nymph of a worker spins its robe in thirty-six hours, and after passing three days in this preparatory state, it undergoes so great a change as to lose every vestige of its previous form. It

is clothed with a harder coating, with dark brown scales, fringed with light hairs. Six annular segments are distinguished on its abdomen, which are inserted one into another like the joints of a telescope tube, and give the insect the power of elongating and contracting itself within certain limits. The breast is also invested with a sort of brush of grey feathery hairs, which as age advances assume a reddish hue. In about twelve days all the parts of the body of the perfect insect are developed, and can be seen through the semi-transparent robe in which it is clothed.

About the twenty-first day, counting from that on which the egg was laid, the second metamorphosis is complete, and the perfect insect, gnawing through the cover of its cell, issues into life, leaving behind it the silken robe which it wore in the intermediate state of nymph. This is closely attached to the inner surface of the cell in which it was woven, and forms a permanent lining of it. By this cause the breeding cells become smaller and smaller, as the eggs are successively hatched in them, until at length their capacity becomes too limited for the full development of the nymphs. They are then turned into store rooms for honey.

Fig. 45.



Pupa of a worker.

107. In fig. 46 is represented a piece of comb, consisting exclusively of workers' cells, in different states. Several, *c*, *c*, *c*, &c., are closed, the nymph not having yet undergone its final metamorphosis. A bee having arrived at the perfect state and gnawed open the

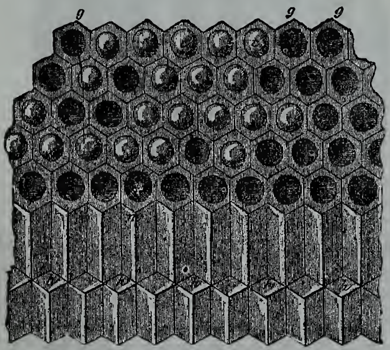


Fig. 46.

cover of its cell, is shown at *m*. The cells, *h*, *h*, have their openings on the opposite side of the comb, and *g*, *g*, *g*, are cells from which the perfect insects have already issued.

108. When a young bee, after its final metamorphosis, has issued from the cell, the nurses crowd round it, carefully brushing it, giving it nourishment and showing it the way through the hive. Others meanwhile are occupied in cleaning the cell from which it has issued and putting it in order to receive another egg if it be still large enough, and if not, to receive a store of honey.

The young bee is not sufficiently strong to fly on the first day. It is only on the morrow, after being well fed and brushed down by the nurses, and having taken a walk from time to time through the combs, that it ventures on the wing.

109. The drone passes three days in the egg, and continues to receive the care of the nurses as a grub until the tenth day, when it passes into the state of nymph, and is sealed up in its cell by the

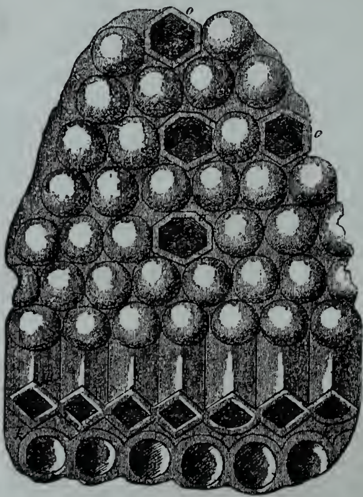


Fig. 47.

nurses with a very convex cover. As already stated, the drone grub being larger than that of the worker, the cell assigned to it is proportionately more capacious, and the cover by which as a nymph it is shut up is much more convex externally. A piece of comb consisting of drone cells is shown in fig. 47.

Some cells, *o*, *o*, *o*, being those from which the perfect insect has issued, are open and empty.

Near the borders of the comb, where local circumstances render it necessary to modify the principles of its architecture so as to accommodate the cells to their position in the hive, may be observed several, *k*, *k*, of unusual and irregular forms. While some such cells have six unequal sides, others have only four or five. It seems also that in the case of certain cells intended only for the reception of honey, the bee is not at all as scrupulous in the observance of architectural regularity as in the case of brood cells.

110. The drone nymph undergoes its final metamorphosis and becomes a perfect insect, from the twenty-fifth to the twenty-seventh day from that on which the egg is laid, according to the temperature of the hive. It is therefore six or seven days later in arriving at maturity than the worker.

111. The changes to which the young of the royal family are subject before arriving at maturity, are different from those above stated. It has been already explained that the royal cells are vertical instead of being horizontal, are egg-shaped instead of being hexagonal, and in fine are much more capacious than those

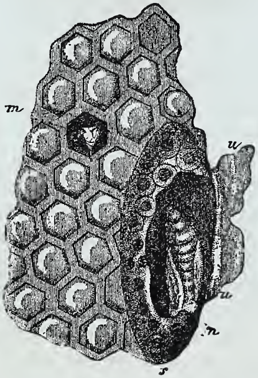


Fig. 48.

of the drones or workers. One of these cells is shown at *r s* in fig. 48, a part, *u u*, being removed to show the royal nymph within it. It will be observed that a much larger space is given to the royal nymph than is allowed either to that of the worker or the drone, the bodies of which nearly fill their respective cells. The royal nymph is always placed, as shown in the figure, with her head downwards.

The progressive formation of a royal cell is shown in fig. 49. It is unfinished, as at *a*, when the egg is deposited; and is gradually enlarged, *c*, as the grub increases in size; and is sealed up, *b*, when it is transformed into a nymph.

The grub issues from the egg on the third day, becomes a nymph from the eighth to the eleventh day, and undergoes its

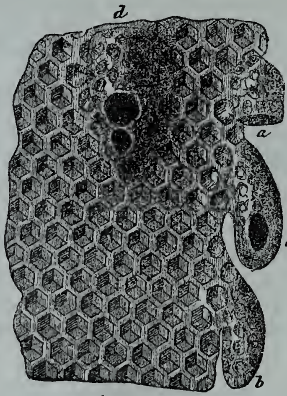


Fig. 49.

final metamorphosis, becoming a perfect insect on the seventeenth day. It is, however, sometimes detained a prisoner in the cell for seven or eight days longer.

112. Naturalists are not agreed as to some of the circumstances attending the treatment of the young, which we have here given on the authority of Feburier and other French entomologists. Mr. Dunbar, in reference to the circumstances attending the first issuing of the perfect insect from the cell, says that in hundreds of instances their situation has excited his compassion, when after long struggling to escape from its cradle, it has at last succeeded so far as to extrude its head, and when labouring with the most eager impatience, and on the very point of extricating its shoulders also, which would have at once secured its exit, a dozen or two of workers, in following their avocations, have trampled without ceremony over the struggling creature, which was then forced for the safety of its head, quickly to pop down again into the cell and wait until the unfeeling crowd had passed, before it could renew its efforts. Again and again will the same impatient efforts be repeated by the same individual, and with the same mortifying interruptions, before it succeeds in obtaining its freedom. Not the slightest attention or sympathy on the part of the workers in these cases was ever observed by Mr. Dunbar, nor did he ever witness the parental cares and sage instruction given to the young which are described by the French entomologists.

Positive, however, is more entitled to consideration than negative testimony, and it cannot be doubted that Feburier and others witnessed those cares, guidance, and education which they have so well described. Besides, Dr. Bevan admits that he has seen assistance rendered to the infant drones. So soon as the young insect has been cleaned of its exuviæ and regaled with honey by the nurses, the latter clean out the cell exactly as we have already described.

113. A piece of comb is shown in fig. 50, the upper part A, of which contains honey-cells closed with flat sides of wax. The cells, *c c*, &c., contain pollen, and *c′ c′*, &c., propolis. The cells

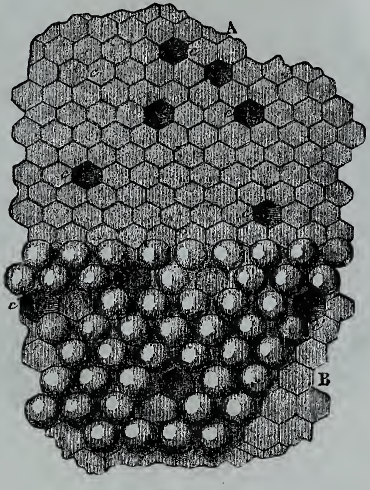


Fig. 50.

of the upper part are those which originally belonged to workers, and those of the lower part, with convex covers, are occupied by the drone nymphs.

114. The various flowers and herbs which supply the materials for honey, wax, and propolis taken collectively, are called the pasturage of the bees, and it is observed that when this pasturage is very abundant, the bees, eager to profit by the rich harvest, depart from their habit of conveying their booty first to the uppermost cells of the comb, so as to fill them gradually downwards. On the contrary, upon arriving with their load, and eager to return for a fresh supply, they unload themselves in the nearest empty cells they can find. The wax-makers meanwhile charge

themselves with the labour of taking the provisions thus deposited from the lower to the upper parts of the combs.

115. In fig. 51, is shown a piece of comb in process of construction. It has, as usual, an oval form. The wax, of which it is formed, is white, but as it advances in age it takes successively a

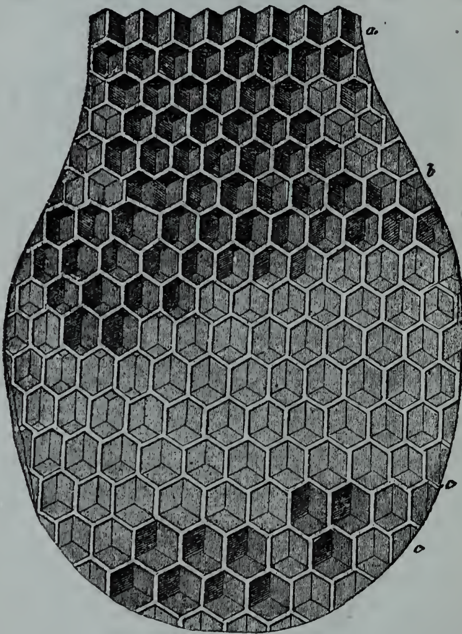


Fig. 51.

darker and darker colour, being first yellow, then reddish, and sometimes even becomes blackish. The sides of the cells are gradually thickened, by the constant adhesion and accumulation of the cocoons, of which the nymphs successively bred in them are divested. The top and sides of the comb are every where strongly cemented, by a mixture of propolis and wax, to the roof and sides of the hive. These structures are almost never known to fall except by some accidental cause external to the hive, such as a blow or the too intense heat of the sun dissolving the cement.

116. The character and manners of the bee have an intimate relation with its social organisation. We have seen that in the

building of their city this organisation is never for a moment lost sight of. The chambers vary in number, magnitude, form, and position. Those designed for the members of the royal family are few and exceptional, those for the drones much more numerous, but about one hundred times less numerous than those of the workers. The magnitudes are in like manner strictly regulated, in relation to the volume of the body of the occupant, except the royal chambers to which a magnitude is given much greater in proportion than that of the bodies of the royal tenants. The object to be attained by this increased capacity, as well as by the vertical position specially given to the royal cells, has not been ascertained.

117. How little relation there exists between mere bodily magnitude, and the faculties which govern acts so remarkable as those of the insects now before us, will be understood when it is stated that, according to the experiments of Reaumur, the average weight of the bee is such that 336 go to an ounce, and 5376 to a pound; and John Hinton found that 2160 workers would not more than fill a common pint.

118. Having thus explained in a general way the persons composing the society, and the structure and architecture of their dwellings, we shall proceed to notice some of the more remarkable traits of their character and manners.

It has been already explained that the community of the hive bees is strictly a female monarchy. The jealous Semiramis of the hive, as Kirby observes, will have no rival near her throne. It may, therefore, be asked to what purpose are the sixteen or twenty princesses reared, for whom royal chambers are provided, and who are treated in all respects by the nurses as aspirants to the throne? This will be comprehended, however, when it is remembered that the hive, soon after the commencement of the season, becomes so enormously over-peopled, that emigration becomes indispensable, and that with each emigrant swarm a queen is necessary. Either therefore the queen regnant must go forth, abdicating the throne, in which case it is ascended by the eldest of the princesses, or the latter is raised to the sovereignty of the emigrating colony. Now, since a rapid succession of swarms issue from the hive, especially in the early part of the season, sometimes as many as four in eighteen days, and since one queen is required for each, a proportionately numerous royal family is required to fill so many independent thrones.

119. When the growth of several princesses and their arrival at maturity occurs, before the increase of the population renders emigration necessary, so as to create thrones for them, the most violent jealousy is excited in the breast of the queen regnant, who is either mother or sister to these several queens presumptive,

and her royal breast is fired with agitation, nor does she rest until she has engaged in mortal conflict with her rivals, and either puts them to death or suffers death at their hands.

120. When a hive, having lost its queen by emigration or otherwise, is provided with several royal cells, which generally happens, the first princess which issues from these in the perfect state immediately ascends the throne in right of primogeniture. Although her rivals are not yet in a condition to dispute the title, they, nevertheless, excite her jealousy in the highest degree. Scarcely ten minutes elapse from the moment she has attained the perfect state, and issued from the royal cell, when she goes in quest of the other royal cells, assails with fury the first she encounters, and having gnawed a large hole in it she introduces the posterior extremity of her abdomen, and kills her rival with her sting.

121. A crowd of workers, who are passive spectators of this, approach the cell, and enlarging the breach, drag out the corpse of the murdered princess, who, in such cases, has already assumed the perfect state. If the queen attack in like manner a cell of which the occupant is still in the state of nymph, she does not waste her strength in slaying it, well knowing that its premature exposure will do the work of death. The workers, in this case also enlarging the breach made by the queen, pull out the nymph, who immediately perishes.

122. Huber, who witnessed, and has described all these curious proceedings, being desirous to ascertain what would happen if two rival queens, both in the perfect state, found themselves together in the same hive, produced artificially that contingency on the 15th May, 1790. He managed to provide in the same hive royal cells, in an equal stage of forwardness, so that virgin queens issued from two of them almost at the same moment.

When they appeared in presence of each other they fell upon each other with all the appearance of insatiable fury, and so engaged one with the other, that each held in her mandibles the antennæ of the other. They were engaged breast to breast, and abdomen to abdomen, so that if each had put forth her sting, mutual death would have been the consequence. But as if nature had forbidden this mutual destruction, the combatants disengaged themselves from each other's grasp, and fled one from the other with the greatest precipitation.

Huber says that this was not a mere incident which might have occurred in a single case, but would not occur in others, for he repeated the same experiment frequently, and it was always followed by the same result. It seemed, therefore, as though it were a case foreseen by nature, and that one only of the combatants should fall in such combats.

123. Nature has ordained that in each hive there shall be one, and but one queen, and when by any concurrence of circumstances a second appears, one or the other is doomed to destruction. But it is not permitted to the common class of the people to do execution on a royal personage, since in that case it might not be possible to secure unanimity as to the particular queen who is to be preserved, so that different assemblages of the people might at the same time assail different queens, and so leave the hive without a sovereign. It was, therefore, necessary, as Huber argues, that the extermination of the superfluous queens should be left to the queens themselves, and that they should in their combats be filled with an instinctive horror of mutual destruction.

Some minutes after the two queens above mentioned had separated and retired from each other, and when their fears had time to subside, they again prepared to approach each other. They engaged once more in the same position, involving the danger of mutual destruction, and as before, once again separated and mutually fled each other.

124. During all this time the greatest agitation prevailed among the population who assisted at the scene, more especially when the two combatants separated. On two different occasions the workers interfered to prevent them from flying from one another. They arrested them in their flight, seizing them by the legs and detaining them prisoners for more than a minute. In fine, in a last attack, one of the queens, more active and furious than the other, taking her rival unawares, laid hold of her with her mandibles at the insertion of the wing, and then mounting on her back, and bringing the posterior extremity of her abdomen to the junction of one of the abdominal segments of her adversary, stabbed her mortally with her sting. She then let go the wing which she had previously held and withdrew her sting.

The vanquished queen fell, dragged her body slowly along for a certain distance, and soon after expired.

125. Having thus ascertained the conduct of virgin queens under the circumstances here described, Huber made arrangements for observing the conduct of queens who were in a condition to produce eggs. For this purpose he placed a piece of comb on which three royal cells had been constructed in a hive with a laying queen. The moment they caught her eye she fell upon them, opened them at their bases, and surrendered them to the attendant workers, who lost no time in dragging out the royal nymphs, greedily devouring the store of food which remained in the cells, and sucking whatever was in the carcases. Having accomplished this they proceeded to demolish the cells.

It was now resolved to ascertain what would be the behaviour of a queen-mother regnant in case a stranger queen pregnant were introduced into the hive. A mark having been previously made upon the back of such a queen, so that she might be afterwards identified, she was placed in the hive. Immediately on her appearance the workers collected in a crowd around her, and formed as usual a circle of which she was the centre, the heads of all the remaining crowd being directed towards her. This very soon became so dense that she became an absolute prisoner within it.

While this was going on, a similar ring was formed by another group of workers round the queen regnant, so that she was likewise for the moment a prisoner.

The two queens being thus in view of each other, if either evinced a disposition o approach and attack the other, the two rings were immediately opened, so as to give a free passage to the combatants; but the moment they showed a disposition to fly from each other, the rings were again closed, so as to retain them in the spot they occupied.

At length the queen regnant resolved on the conflict, and the surrounding crowd, seeming to be conscious of her decision, immediately cleared a passage for her to the place where the stranger stood perched on the comb. She threw herself with fury on the latter, seized her by the root of the wing, and fixed her against the comb so as to deprive her of all power of movement or resistance, and then bending her abdomen inflicted a mortal stab with her sting, and put an end to the intruder.

Fig. 52.

126. A fruitful queen full of eggs was next placed upon one of the combs of a hive over which a virgin queen already reigned. She immediately began to drop her eggs, but not in the cells; nor did the workers, by a circle of whom she was closely surrounded, take charge of them; but, since no trace of them could be discovered, it is probable that they were devoured.

The group, by which this intruding queen was surrounded, having opened a way for her, she moved towards the edge of the comb, where she found herself close to the place occupied by the legitimate virgin queen. The moment they perceived each other, they rushed together with ungovernable fury. The virgin, mounting on the back of the intruder, stabbed her several times in the abdomen, but failed to penetrate the scaly covering of the segments. The combatants then, exhausted for the moment, disengaged themselves and retired. After an interval of some minutes they returned to the charge, and this time the intruder succeeded in mounting on the back of the virgin and giving her several stabs with her sting, which, however, failed to penetrate the flesh. The virgin queen, succeeding in disengaging herself, again retired. Another round succeeded, with the like results, the virgin still coming undermost, and, after disengaging herself, again retiring. The combat appeared for some time doubtful, the rival queens being so nearly equal in strength and power, when at last, by a lucky chance, the virgin sovereign inflicted a mortal wound upon the intruder, who fell dead on the spot.

In this case, the sting of the virgin was buried so deep in the flesh of her opponent, that she found it impossible to withdraw it, and any attempt to do so by direct force would have been fatal to her. After many fruitless efforts she at length adopted the following ingenious expedient with complete success. Instead of exerting her force on the sting by a direct pull, she turned herself round, giving herself a rotatory motion on the extremity of her abdomen where the sting had its insertion, as a pivot. In this way she gradually *unscrewed* the sting.

127. The gates of the hive are as constantly and regularly guarded night and day as those of any fortress. The workers charged with this duty are, of course, regularly relieved. They scrupulously examine every one who desires to enter; and, as though distrustful of their eyes, they touch all visitors with their antennæ. If a queen happens to present herself among such visitors, she is instantly seized and prevented from entering. The sentinels grasp her legs or wings with their mandibles, and so surround her that she cannot move. As the report of the event spreads through the interior of the hive, large reinforcements of the guard arrive, who augment the dense ranks which hold the strange queen in durance.

In general, in such cases, the intruding queen is thus detained prisoner until she dies from want of food. It is remarked that the guard, who thus surround and detain her, never use their stings upon her. In one instance Huber attempted to extricate a queen, thus surrounded, by taking her directly out of the ring of guards. This excited the rage of the guard to such a pitch that, putting forth their stings, they rushed blindly not only on the queen but on each other. The queen, as well as several of the guard, were killed in the mêlée.

128. When the sovereign of the hive is removed or accidentally destroyed, the population seem at first to be wholly unconscious of their loss, and pursue their usual avocations as if nothing had happened. But after the lapse of some hours they begin to manifest a certain degree of uneasiness. This gradually increases,

until the entire hive becomes a scene of tumult. The wax-makers abandon their work, the nurses desert the infant brood; they run here and there in all directions through the streets and passages of the hive as if in delirium. That all this disorder and alarm is produced by the report spreading that the sovereign has disappeared, was proved to demonstration by Huber, who restored to the hive the queen he had purposely withdrawn. Her majesty was instantly recognised by those who happened to be assembled at the place of her restoration; but what is remarkable is that the intelligence of her return was immediately spread through every part of the hive, so that the bees in its most remote streets and alleys, who had no opportunity of personally seeing her majesty, were informed of her re-appearance, as was proved by the restoration of order and tranquillity, and the resumption of their usual labours by all classes of the population.

129. If, instead of restoring to the hive the queen herself, a new queen, stranger to the population, be introduced, she will not at first be accepted. She will, on the contrary, be guarded and imprisoned by a ring of bees, in the same manner as a strange queen is treated in a hive which still retains its reigning sovereign. But if she survives sixteen or eighteen hours in this confinement, the guard around her gradually disperses itself, and the lady enters the hive and assumes without further question the state and dignity of queen, and becomes the object of the homage paid to the sovereign.

As we have already stated, the first work which the population undertakes, after being assured of the loss of its queen, is directed to obtain a successor to her. If there be not royal cells prepared, they set about their construction. While this work was in progress, and in twenty-four hours after their queen had been taken from them, Huber introduced into the hive a fruitful queen in the prime of life, being eleven months old. Not less than twelve royal cells had been already commenced and were in a forward state. The moment the strange queen was placed on one of the combs, one of the most curious scenes commenced which was probably ever witnessed in the animal world, and which has been described by Huber.

The bees who happened to be near the stranger approached her, touched her with their antennæ, passed their probosces over all parts of her body, and presented her with honey. Then they retired, giving place to others, who approached in their turn and went through the same ceremony. All the bees who proceeded thus clapped their wings in retiring and ranged themselves in a circle round her, each, as it completed the ceremony, taking a position behind those who had previously offered their respects. A general agitation was soon spread on those sides of the combs corresponding with that of the scene here described. From all quarters the bees crowded to the spot, and each group of fresh arrivals broke their way through the circle, approached the new aspirant to the throne, touched her with their antennæ and probosces, offered her honey, and, in fine, took their rank outside the circle previously formed. The bees forming this sort of court circle clapped their wings from time to time, and fluttered apparently with self-gratification, but without the least sign of disorder or tumult.

At the end of fifteen or twenty minutes from the commencement of these proceedings the queen, who had hitherto remained stationary, began to move. Far from opposing her progress or hemming her in, as in the cases formerly described, the bees opened the circle on the side to which she directed her steps, followed her, and, ranging themselves on either side of her path, lined the road in the same manner as is done by military bodies in state processions. She soon began to lay drone eggs, for which she sought and found the proper cells in the combs which had been already constructed.

While these things were passing on the side of the comb where the new queen had been placed, all remained perfectly tranquil on the opposite side. It seemed as though the bees on that side were profoundly ignorant of the arrival of a new queen on the opposite side. They continued to work assiduously at the royal cells, the construction of which had been commenced on that side of the comb, just as if they were ignorant that they had no longer need of them; they tended the grubs in those cells where the eggs had been already hatched, supplying them as usual, from time to time, with Royal Jelly. But at length the new queen in her progress arriving at that side of the comb, she was received by those bees with the same homage and devotion of which she had been already the object at the other side. They approached her, coaxed her with their antennæ and probosces, offered her honey, formed a court circle round her when she was stationary, and a hedge at either side of her path when she moved, and proved how entirely they acknowledged her sovereignty by discontinuing their labour at the royal cells, which they had commenced before her arrival, and from which they now removed the eggs and grubs, and ate the provisions which they had collected in them.

From this moment the queen reigned supreme over the hive, and was treated in all respects as if she had ascended the throne in right of inheritance.

130. Most of the proceedings of these curious little societies are explicable by what seems a general social law among them, to

suffer no individuals or class to continue to exist, save such as are necessary in one way or another to the well-being of the actual community, or the continuance of the species. This principle once admitted, we find explanations satisfactory enough of all the circumstances attending the conduct of the queen regnant towards the royal princesses, of the population generally to the several members of the royal family, and, in fine, of the workers towards the drones.

The royal family, as we have seen, are all fertile females, and their sole function is to assume the throne of the hive itself, or of the colonies called swarms, which successively issue from it, and thus placed to become the fruitful mothers of thousands, which will continue the race and form future colonies.

The drones have no other function than that of kings consort presumptive, either of the hive itself or of the colonies which successively emigrate from it. As has been explained, one only is chosen as consort by each queen. So long as the swarming season continues, a sufficient body of drones are wanted to supply the necessary troop of suitors to each emigrant princess. But when the last swarm of the season has gone forth, and the queen regnant has long since made her choice and celebrated her nuptials, the drones are no longer useful to the general population, and become the objects of a general massacre.

131. After the close of the winter, and at the commencement of the first fine days of spring, the active life of the society recommences. A well peopled hive is then always provided with a fertile queen, who has held the sovereignty since the close of the preceding season. In the months of April and May she begins to lay drone eggs in great numbers. This is called the great laying.

While she is thus engaged depositing her eggs in the larger class of hexagonal cells, previously constructed for their reception, the workers, well knowing that the deposition of royal eggs will speedily follow, occupy themselves in constructing a number of those cells of oval shape and vertical position, (fig. 49,) which have been already described.

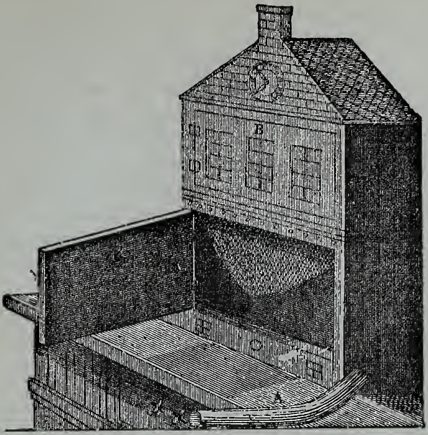


Fig. 56.—THE CABINET BEE-HOUSE.

THE BEE.

ITS CHARACTER AND MANNERS.

CHAPTER V.

132. Change of state of the queen after laying.—133. First swarm led by her majesty.—134. Proceedings of the first swarm.—135. Loyalty and fidelity to the queen—remarkable experiment of Dr. Warder.—136. Interregnum after swarming.—137. The princess royal.—138. Second swarm—its effects. —139. Successive swarms.—140. Production of a factitious queen—Schirach's discovery.—141. Factitious queens dumb.—142. Factitious princesses allowed to engage in mortal combat.—143. Homage only offered to a married queen.—144. Respect shown to her corpse.—145. Functions of the drones.—146. Their treatment.—147. Their massacre described by Huber.—148. Case in which no massacre took place.—149. Character and habits of the workers.—150. Products of their labours.—151. Process of work. 152. Honey and pollen—nectar and ambrosia.—153. Bee the priest who celebrates the marriage of the flowers. —154. Why the bee devotes each excursion to one species of flower.—155. Unloading the workers.—156. Storage of spare provision.—157. Radius of the circle of excursion.

To make this great laying of drone eggs, her majesty must be at least eleven months old. Supposing that she has been hatched the preceding season in February, she will lay during that season workers' eggs almost exclusively, producing at the most from fifty to sixty drone eggs. But after the winter, at the epoch now referred to, the hive being then filled exclusively with workers, and standing in absolute need of drones to supply suitors to the future queens, she produces drone eggs constantly and exclusively until the commencement of the swarming season, with the exception, however, of a limited number of royal eggs, which she deposits at intervals more or less distant in the royal cells just now mentioned, which the workers occupy themselves in constructing during the great laying.

The great laying usually continues for about a month, and it is about the twentieth or twenty-first day that the workers begin to lay the foundations of the royal cells. They generally build from sixteen to twenty of them, and sometimes even as many as twenty-seven. When these cells have attained the depth of two-tenths to three-tenths of an inch, the queen deposits in each of them successively a royal egg. Now since the princesses which are to issue from these eggs are destined to ascend the thrones of the emigrant colonies, which are to issue in succession from the hive, it is important that they should arrive at maturity at successive intervals, corresponding as nearly as possible with the emigration of the swarms.

The queen acts as if she were conscious of this, for she deposits the royal eggs, not like the drone or worker eggs in rapid and uninterrupted succession, but after such intervals as will insure their arrival at maturity in that slow succession, which will correspond nearly or exactly with the issue of the successive swarms.

132. It has been already explained that the nurses seal up the cells, at the time at which the grub is ready to undergo its metamorphosis into a nymph. In accordance with this, and with the successive deposition of the royal eggs, just described, the times of sealing up the series of royal cells are separated by intervals corresponding with those of the deposition of the royal eggs.

Before the commencement of the great laying, the abdomen of the queen is so enlarged that her movements are seriously impeded, and she would be altogether unable to fly. According as the laying proceeds, she becomes smaller and smaller, and when it has been completed, the royal eggs having been meanwhile deposited at regulated intervals, as above described, her majesty recovers her natural form and dimensions, and with them her full bodily activity. This change in the condition of the queen, and the simultaneous deposition of fifteen hundred to two thousand drone eggs, and some sixteen or twenty royal eggs, are intimately connected with the approaching social state of the colony.

133. It was shown by Huber, and since confirmed by other observers, that it is a constant law of bee politics that the first swarm of the season shall be led by the queen-regnant, who therefore abdicates her native throne in favour of the colonial sovereignty. This swarm takes place when the grub proceeding from the first of the eggs deposited by the queen in the royal cells, as above described, has undergone its transformation into a nymph.* The necessity for this law is thus explained by Huber. Without it, the mutual conflict of the queen-regnant and the princesses, as they would be successively developed, would render the emigration of swarms impossible. For as each princess would issue perfect from the cell, she would be attacked, and forced to engage in combat with the queen, who being, by reason of her age, the stronger and more powerful, would be always victorious. Thus princess after princess would be destroyed, and none would be forthcoming to take the thrones of the successive emigrating colonies. To prevent such a catastrophe, nature has therefore wisely ordered that the queen-regnant, by leading forth the first swarm of the season, should remove all cause of danger to the succession of princesses.

134. When the emigrant swarm thus first sent forth from the parent hive has established itself, the first care of the workers is to construct combs, consisting of workers' cells. They labour assiduously at these, and in accordance with this the queen, who has already deposited in the original hive her full brood of drone eggs, soon begins in her new city to deposit a brood of worker eggs; workers being then the first and most pressing want of the colony. This laying begins as soon as the cells are ready for the deposition of the eggs, and continues for ten or twelve days. About the latter part of this interval, the bees occupy themselves in the construction of the larger class of hexagonal cells for the drone eggs. It would seem as though they knew that her majesty would at this time lay a certain number of such eggs. She accordingly commences laying these, though in far less number than in the great laying, but still sufficient to prepare her people for the succeeding deposition of royal eggs, for which they construct meanwhile a suitable number of royal cells.

It rarely happens, at least in the country where Huber made his observations, that the original queen leads forth a swarm from the new hive. The thing nevertheless occasionally occurs, and when it does, it takes place in three or four weeks after the

* Huber, i. 279.

original swarm, and is attended with circumstances precisely similar.

135. Let us now return to the original hive and see what took place there after the departure and abdication of the reigning queen.

As examples proving the loyalty and fidelity of the bees to their queen, Dr. Bevan quotes some remarkable and interesting cases supplied by Dr. Warder. That apiarist being desirous of ascertaining the extent of the loyal feeling among these little people, hazarded the loss of a swarm in an experiment made with that object. Having shaken on the grass all the bees from a hive which they had tenanted only the preceding day, he carefully sought for and quietly caught the queen. Then placing her with a few attendants in a box, he took her into his parlour, where the lid being removed, she and her attendants immediately flew to the window, when he clipped off one of her wings, returned her to the box and confined her there for more than an hour.

In less than a quarter of an hour the swarm ascertained the loss of their queen, and instead of clustering together in a single mass as usual, like a bunch of grapes, they spread themselves over a space of several feet, were much agitated, and uttered a plaintive sound. An hour afterwards they all took flight and settled upon the hedge where they had first alighted after leaving the parent stock, but instead of clustering together in a single bunch, as when the queen accompanied them, and as swarms usually hang, they extended themselves thirty feet along the hedge in small bunches of forty or fifty or more.

The queen was now presented to them, when they quickly gathered round her with a joyful hum, and formed one harmonious cluster. At night the Doctor hived them again, and on the next morning repeated the experiment to see whether the bees would rise. The queen being in a mutilated state, and unable to accompany them, they surrounded her for several hours apparently willing to die with her rather than abandon her in her distress. The queen was a second time removed, when they spread themselves out again, as though in search of her. Her repeated restoration to them at different parts of their circle produced one uniform result, and these poor loving and loyal creatures always marched and counter-marched every way as the queen was laid. The Doctor persevered in these experiments, till, after five days and nights of voluntary fasting, they all died of inanition except the queen, and she survived her faithful subjects only a few hours.

This remarkable attachment between queen and subjects appears to be reciprocal the sovereign being as strongly sensible of it as those over whom she rules. Though offered honey on several occasions during her temporary separation from the swarm in these experiments, she constantly refused it, disdaining a life which was no life to her, deprived of the society of her faithful people.*

136. After the departure of her majesty there seems to be a sort of interregnum in the hive during the succession of swarms. No new sovereign is for the moment elevated to the throne. A strong guard is established at each of the royal cells, whose duty it is to confine the princesses with the utmost rigour to their respective cells, carefully feeding them, and only liberating them at intervals of some days according to the successive departure of the swarms. They are liberated in the strict order of their seniority, the nymph proceeding from the first royal egg, or the princess royal, being invariably the first set free.

137. When she issues forth, her first impulse, like that of all queens, is to fall upon the cells containing her younger sisters to destroy them. This, which in other states of the colony is permitted by the workers, is now strenuously and effectually opposed by them. When she approaches the neighbourhood of the royal cells, the guard in whose charge these are placed, pinch, worry, and hunt her until they compel her to depart, but never attempt to assail her with their stings or seriously injure or disable her.

Now, as there are usually a great number of these royal cells in different parts of the hive, our princess finds it a difficult matter to obtain any corner where she can remain unmolested. Incessantly impelled by her instinct to attack the cells of her sisters, and as incessantly repulsed from them by the surrounding guard, her life is rendered miserable. She is in a constant state of agitation, running from one group of workers to another, until at length the agitation is shared by a certain portion of the workers themselves. When this occurs, a crowd of bees are seen rushing towards the portals of the city. They issue from it accompanied by their young and virgin queen. It is the second swarm of the season, and differs from the first only in the age and condition of its sovereign.

138. After this emigration the workers, who have remained in possession of the hive liberate another of the princesses, the second in seniority, whom they treat exactly in the same manner as the former. The same succession of repulses by the guards of the remaining royal cells takes place, attended by like consequences, this second princess leading forth in the same manner the third swarm, and so on.

139. This spectacle is repeated three or four times in the season

* Bevan, p. 148.

in a well-peopled hive, until the population is so reduced that the number necessary to form a sufficient guard upon the royal cells can no longer be spared from the general industry of the hive. Several princesses then escape from the cells, nearly at the same time, who fall upon each other in the manner already described, being now encouraged instead of being opposed by the workers. In fine, all but one fall in those combats, and this fortunate survivor, who is in general the eldest of the princesses remaining in the hive, ascends the throne, and is acknowledged by the whole community.

According to Huber, swarms issue from the hive only in sunshine and a calm atmosphere. After all the precursors of a swarm have appeared, a passing cloud often arrests it, and the intention of the bees seems to be abandoned. An hour later the appearance of the bright sun will reproduce all the usual movements, and the swarm will issue.

Many conjectures are made as to the means by which the workers know so well, as they undoubtedly do, the relative ages of the several princesses, so as to liberate them according to seniority. Huber conjectures that a peculiar sound, which they produce before their liberation from the cells, and which he thought varied in loudness and pitch, might be the distinguishing character of relative age.

140. A contingency arises occasionally in the bee community, which we have not yet noticed, and which is attended with consequences of a very curious and interesting nature. It was discovered by Schirach, and confirmed by numerous and long continued observations of Huber, that when by any cause a colony loses its queen, without having any royal cells or royal eggs previously provided, they are enabled by certain extraordinary processes and expedients to produce princesses, among whom they may obtain a successor to their last sovereign.

M. Schirach, Secretary of an Apiarian society, at Little Bautzen in upper Lusatia, observed that bees, when shut up with a portion of comb containing worker brood only, would soon construct royal cells, into which they would put worker eggs, the grubs from which, being nourished with royal jelly, would grow up as queens. This remarkable result is known among apiculturers as the Lusatian experiment. This experiment has since been repeated thousands of times, and always with the same results by all the most eminent naturalists who have directed their researches to this part of entomology, and indeed generally by all bee cultivators. So that of the fact itself, strange and incredible as it may seem, there is not the faintest shadow of doubt.

The following is the process by which this miracle of nature is performed.

Having chosen a worker grub, from one to three days old, the workers pull down two of the cells adjacent to that in which the chosen grub lies. They pull down the walls which separate these three chambers, so as to throw them into one three times more spacious than the single cell of the grub. Leaving the pyramidal bases of these three cells untouched, they construct around the grub a large cylindrical tube, which is consequently included within the remaining walls of the three demolished cells, the axis of the tube being parallel to that of the cells, and therefore horizontal.

It seems, however, that to accomplish the desired change on the nature of the grub, it is not only necessary to give it an enlarged cell, but one of which the axis is vertical instead of being horizontal. On the third day, therefore, from the commencement of their operations, they take measures to cement to the horizontal tube a vertical chamber having a conical form, making with the horizontal tube an elbow. To accomplish this they gnaw away several cells below the end of the tube, sacrificing without mercy the grubs which occupy these, as well as those which occupied the two cells adjacent to the original cell of the chosen grub.

This rectangular cell, therefore, composed of the original cylindrical, and the more recently constructed conical cell, may be considered as having some such form as here roughly sketched,

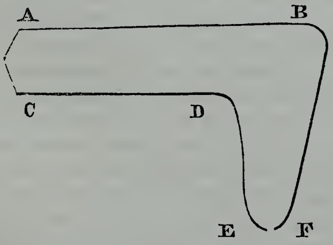


Fig. 53.

(fig. 53,) where A B C D is the horizontal cylindrical part formerly filled by three worker hexagonal cells, and B F E D, the vertical conical part, subsequently cemented to it, and built with the wax obtained from the demolition of the worker cells under A B C D.

During two days which the grub inhabits this vertical cell, B F D E, a nurse may always be observed with its head plunged into it, and when one quits it another takes its place, thus relieving each other with all the regularity of military sentinels. These bees keep constantly lenthening the cell, B F E D, as the grub grows older, and duly supply it with food, which they place before its mouth and round its body. The animal, which can only move in a spiral direction, keeps turning to take the jelly deposited before it, and thus slowly working downwards, arrives insensibly nearer the orifice of the cell, just at the time that it is ready to be metamorphosed into a nymph. At this moment, the workers, conscious of the impending change, seal up the mouth E F of the cell, and cease their attentions, leaving nature to effect the last transformation.

One of these cells is shown at *d*, in fig. 49.

That the mere change in the quality of the food, combined with the increased capacity and altered form of the cradle, should be the means of producing a transformation, so extreme as that from a worker to a queen, must be a matter of profound astonishment to every reflecting mind; so much so indeed, that without the most incontestable evidence, and the power moreover of reproducing the phenomenon at will, it could not be credited. Let any one imagine how such an assertion as this, that the foal of an ass by a particular sort of provender, and by being reared in a stable of particular magnitude and form, could be made to grow into a through bred horse, would be received. Yet, such a transformation produced by such means would not be one whit more wonderful than the change of a worker grub into a queen-bee, by the means just stated. "What!" says Kirby, addressing his correspondent, "you will ask, can a larger and warmer house, a different and more pungent food, and a vertical instead of an horizontal posture, give a bee a different-shaped tongue and mandibles; render the surface of its under-legs flat instead of concave; deprive them of the fringe of hairs that forms the basket for carrying the masses of pollen,—of the auricle and pecten which enable the workers to use these legs or feet as pincers,—of the brush that lines the insides of the feet? Can they lengthen its abdomen; alter its colour and clothing; give a curvature to its sting; deprive it of its wax pockets; and of the vessels for secreting that substance; and render its ovaries more conspicuous and capable of yielding worker and drone eggs?"

In the next place, can the apparently trivial circumstances just mentioned alter altogether the instincts of these creatures? Can they give to one description of animals address and industry, and to the other astonishing fecundity? Can we conceive them to change their very passions, tempers, and manners? That the very same fœtus, if fed with more pungent food, in a higher temperature, and in a vertical position, shall become a female, destined to enjoy love, to burn with jealousy and anger, to be incited to vengeance, and to pass her time without labour—that this very same fœtus, if fed with more simple food, in a lower temperature, in a more confined and horizontal habitation, shall come forth a worker, zealous for the good of the community, a defender of the public rights, enjoying an immunity from the stimulus of sexual appetite and the pains of parturition—laborious, industrious, patient, ingenious, skilful,—incessantly engaged in the nurture of the young, in collecting honey and pollen; in elaborating wax; in constructing cells, and the like; paying the most respectful and assiduous attention to objects which, had its ovaries been developed, it would have hated and pursued with the most vindictive fury until it had destroyed them! Further, that these factitious queens, thus produced from worker eggs treated as above described, shall differ remarkably from the natural queens proceeding from royal eggs in being altogether mute! All this must seem so improbable, and next to impossible, that it would require the strongest and most irrefragable evidence to establish it.*

141. It will be remembered that the princesses, when forcibly confined to their native cells by the workers on guard over them, after they have undergone the last transformation, utter a peculiar sound, to the varieties of which Huber ascribes the power of the workers to determine their relative ages. Kirby in the observations just quoted, refers to this, when he indicates one of the distinctions between the factitious and natural queens, the former never uttering these or any other sounds.

142. Another remarkable distinction between the factitious and natural queens is indicated by Huber; no guard is kept at the doors of the cells of factitious princesses, like that which has been already described in the case of the cells of natural princesses. The factitious princesses, unlike the natural, are not detained in their cells after they have undergone the last transformation, but are allowed to issue forth, if they have not been already destroyed by the jealous rage of the first which comes to life.

This peculiarity in the policy of the hive may be explained by the fact, that while the natural princesses are wanted to take the sovereignties of the successive swarms, the factitious ones are only produced to meet the extraordinary emergency of the hive being deprived of its queen, leaving behind her no royal brood, and since only one queen is wanted, the factitious princesses are allowed, and indeed encouraged, by the workers to engage in

* Kirby, Int., vol. ii. 110.

martial conflict until one only survives, who assumes the throne of the hive.

143. The circumstances and anecdotes related by observers illustrative of the affection, devotion, and respect manifested towards the queen by her subjects are innumerable. In addition to those which we have already given, the following will be read with interest.

All the devotion, it must be observed, commences only after the royal nuptials. A virgin queen is treated with indifference the most absolute. But after her marriage has been celebrated, and she presents herself to her subjects in the double character of sovereign and mother, they more than respect her. "They are," says Reaumur,* "constantly on the watch to make themselves useful to her, and to render her every kind office. They are for ever offering her honey. They lick her with their proboscis, and wherever she goes she has a court to attend her."

144. The same naturalist relates that even the inanimate body of the queen is an object of tenderness and affection to the bees. He took one out of the water quite motionless and seemingly dead. It was also mutilated, having lost part of one of its legs. Bringing it home, he placed it among some workers that he had found in the same situation, most of which he had recovered by means of warmth, some, however, being still in as bad a state as the poor queen. No sooner did these revived workers perceive the latter in this wretched condition than they appeared to compassionate her case, and did not cease to lick her with their tongues till she showed signs of returning animation; which the bees no sooner perceived than they set up a general hum as if for joy at the happy event. All this time they paid no attention to the workers, who were in a most miserable condition.†

145. In the economy of the bee, there is nothing which presents more difficulty to the naturalist than the satisfactory explanation of the functions of the drones. These, as has been already explained, are the sole male members of the society; the queen being the sole fertile female; and the workers, though female, exercising none of the functions of that sex, and being limited to the industrial and parental duties of the society. The number of drones in a single society is from 1500 to 2000, one only of whom can enjoy the honour of elevation to the distinguished position of king consort, and that one, as already explained, never surviving the day of the nuptials. What then, it may well be asked, are the services rendered to the community by these hundreds of consumers of the products of the industry of the society? They never themselves take part in the common labours. They neither

* Reaumur, v. 262. † Reaumur, v. 265.

collect food nor materials, nor do they aid in any way in the construction of the dwellings, nor in the care or nurture of the young. In the absence of any better explanation of their vast number it has been said that the purpose is to insure a consort to the queen. But surely this object might be effected without encumbering the society with 2000 candidates for the royal favour.

It has been suggested by some apiarists that the drones may sit upon the eggs, and by others that their use may be to develope heat sufficient to maintain the hive at the necessary temperature; but the experiments and observations of other naturalists have set aside these hypotheses.

146. Whatever be the purpose which this section of the society is destined to fulfil, their treatment by the people, and the manner in which their existence is terminated, are remarkable.

So long as swarms continue to issue from the hive, drones are wanted to supply the necessary proportion of that class to accompany them. But after the swarming season closes, which in these climates it generally does towards the end of July, at least in dry summers, the general massacre of the drones takes place. At that time the bees are seen hunting them in all parts of the hive, and driving them to the base upon which it stands. Soon after this the stand and the ground before the hive are found to be covered with the bodies of hundreds of the murdered drones. It was supposed by Bonnet that no direct massacre was executed, but that the drones driven from the stores of their food died of starvation.*

147. Huber, however, among his other numerous discoveries, contrived to witness, through the eyes of his faithful Burnens, the actual massacre.

At the season at which the extermination usually took place, he placed upon plates of glass six populous hives occupied by swarms of the preceding year, and Burnens lying on his back under the hives was enabled to witness all that took place by the transparency of their bases. On the 4th of July, 1787, he witnessed the massacre, which took place at the same hour in all the six hives. The base was crowded with bees, who appeared in a state of great excitement. As fast as the drones, hunted by other bees from the superior parts of the combs, arrived at the base, the bees there assembled fell upon them, seizing them by their antennæ, legs, or wings, and after dragging them about with apparent rage, put them to death by stabbing them with their stings between the segments of the abdomen. The moment they were thus pierced, they spread their wings and expired. However,

* Bonnet, "Contemplation de la Nature," chap. xxvi. part. xi.

as if the workers did not feel sufficiently certain of their fate, they continued to pierce their bodies with their stings, and often drove these formidable weapons in so deep that they could only extricate them by unscrewing them in the manner already described (126).

The next day they resumed their observations, when a most curious spectacle presented itself. During three hours they saw the massacre of drones, which had been resumed with the same fury, continued. On the preceding day they had exterminated all the drones of their own hives; but this time their attack was directed against those of neighbouring hives, which, having fled, had taken refuge in these, after the massacre of the preceding day had been concluded.

Not content with this complete extermination of the drones themselves, the workers resorted to the cells in which drone nymphs were contained, which had not yet completed their final transformation. These they pitilessly dragged forth, killed, sucked the juices contained in their bodies, and then flung the carcasses out of the hives.

148. It was also ascertained by Huber, that in hives deprived of their queen, or in which the queen, by reason of retarded fecundation, only laid drone eggs, no massacre ever took place. In such hives the drones not only find a sure refuge, but are carefully nurtured and fed.

This circumstance, combined with the fact that the massacre never takes place until after the swarming season is over, seems to indicate the functions of the drones. They are useful only where candidates for the royal nuptials are likely to be wanted.

149. The most interesting class of the bee community is also that which is by far the most numerous, the workers. Indeed, to this class all others must be regarded as subordinate, just as in human societies all are dependent on the producing classes. Much respecting their character, habits, and manners, in relation to the care of their young, and the construction of the city, in a word in respect to their internal labours, has been already explained. Something now must be said of their external industry, directed to the collection of provisions for the community, young and old, and of the materials necessary for the prosecution of all their various works, labours which have been illustrated by Professor Smyth in the following beautiful lines:—

"Thou cheerful bee! come, freely come,
And travel round my woodbine bower;
Delight me with thy wandering hum,
And rouse me from my musing hour.

Oh ! try no more those tedious fields,
Come taste the sweets my garden yields ;
The treasures of each blooming mine,
The bud, the blossom—all are thine.

" And, careless of this noontide heat,
I'll follow as thy ramble guides ;
To watch thee pause and chafe thy feet,
And sweep them o'er thy downy sides ;
Then in a flower's bell nestling lie,
And all thy envied ardour ply !
And o'er the stem, though fair it grow,
With touch rejecting, glance and go.

" Oh, Nature kind ! Oh, labourer wise !
That roam'st along the summer's ray,
Glean'st every bliss thy life supplies,
And meet'st prepared thy winter day !
Go, envied, go—with crowded gates
The hive thy rich return awaits ;
Bear home thy store, in triumph gay,
And shame each idler of the day."

150. The immediate objects to which the exterior industry of the bee is directed, are *nectar*, *pollen*, and *propolis.*

Nectar is a specific juice, found in certain classes of flowers, from which the bee elaborates honey and wax.

Pollen is a peculiar powder, or dust, spread over the anthers of flowers, which constitutes the principle of fecundation of the flowers themselves, and is the material of which the bee makes bread, which serves as food both for old and young.

Propolis is a resinous substance, evolved by certain vegetables which the bee uses as cement, mortar, or glue, in its architecture. When the bee pierces the vessels of the flowers, which, containing nectar, are called nectarines, and swallows that precious juice, it is deposited provisionally in the honey-bag already described (26) ; sometimes called, on that account, the first stomach. Here this nectar is converted into honey, the chief part of which is regurgitated, to be stored up for future general consumption in the honey-cells of the combs.

In the stomach, properly so called (26), and in the intestines, the bread only is found.

How the wax is secreted, physiologists have not yet discovered with any certainty. It is evident, however, that the immediate seat of its production is within the abdomen, since the parts called wax-pockets, from which it is externally evolved, are rendered visible by pressing the abdomen so as to make it extend itself. A pair of quadrangular whitish pockets, of soft membranaceous texture, will then be seen on each of the four middle ventral, segments. On these the plates of wax are formed, and are found upon them in different states so as to be more or less perceptible.

151. Observe a bee, says Kirby, that has alighted on a flower. The hum produced by the motions of her wings ceases, and her work begins. In an instant she unfolds her tongue, which was previously rolled up under her head. With what rapidity does she dart this organ between the petals and the stamina! At one time she extends it to its full length, then she contracts it; she moves it about in all directions, so that it may be applied to the concave and convex surface of the petal, and sweep them both, and thus by a virtuous theft, she robs it of all its nectar. All the while this is going on, she keeps herself in a state of constant vibratory motion.

Flowers, though the chief, are not the only sources from which the bee derives the material of honey and wax. She will also eat sugar in every form, treacle, the juice secreted by aphides; and, in fine, the juice of the bodies of nymphs and of eggs of bees themselves, as already explained.

152. When the industrious little creature has filled its honey-bag with nectar, it proceeds to collect the pollen, of which it robs the flowers by brushing it off with the feathery hairs with which its body is covered. As the honey is called the NECTAR, so this pollen, or the substance bee-bread, into which it is converted, may be called the AMBROSIA of the hive. Together they constitute the food and the drink of the population.

When the bee has so rolled itself in this farina of the blossoms of the garden and the field, that its whole body is so powdered with it, as to give it the peculiar colour of the species of flowers to which it happens to resort, it suspends its excursions, and sets about to brush its body with its legs, which, as already explained, are supplied with brushes for this express purpose. Every particle of the flower thus brushed off is most carefully collected and kneaded up into two little masses, which are transferred from the fore to the hind legs, and there packed up into the baskets provided for its reception and transportation.

Naturalists generally are of opinion that in each of its excursions a bee confines its foraging operations to a single species of flower. This explains the fact that the colour of their load after such excursions is uniform, depending on the particular species of flower which they have robbed of its sweets. Thus, according to Reaumur, some bees are observed to return loaded with red pellets on their thighs, others with yellow, others whitish, and others with green.

Kirby observes, that it seems probable that the bee confines its operations in such excursions to flowers of the same species, and that the grains of pollen which enter into the same mass should be homogeneous, and consequently fitted by their physical properties to cohere with greater facility and firmness.

153. But connected with this, another important purpose of nature is fulfilled, which must not here pass without special notice. The principle, so fruitful in important social consequences among animals, that the offspring owes its parentage jointly to two individuals of different sexes, or, in other words, must always have a father and a mother, equally prevails in the vegetable kingdom. There also are the gentlemen and ladies, there also are the loves which unite them, loves which as well as those of superior orders of beings have supplied a theme for poets.* Now among the many other interesting offices with which the Author of nature has invested the little creatures, which form the subject of this notice, not the least singular is that of being the priests who celebrate the nuptials of the flowers. It is the bee literally which joins the hands and consecrates the union of the fair virgin lily and the blushing maiden rose with their respective bridegrooms. The grains of pollen which we have been describing are these brides and bridegrooms, and are transported on the bee from the male to the female flower; the happy individuals thus united in the bands of wedlock being the particular grains, which the bee lets fall from its body on the flower of the opposite sex, as it passes through its blossom.

154. And here we find another circumstance to excite our admiration of the wise laws of that Providence, which cares for the well-being of a little flower, as much as for that of a great lord of the creation. If the bee wandered indifferently from flower to flower without selection, the gentlemen of one species would be mated with the ladies of another, hybrid breeds would ensue, and the confusion of species would be the consequence. But the bee, as knowing this, flies from rose to rose, or from lily to lily, but never from the lily to the rose, or from the rose to the lily.

155. When a bee, laden with pollen, arrives in the hive, she sometimes stops at the entrance, and leisurely detaching it piecemeal from her legs, devours it bit by bit. Sometimes she passes into the hive and walks over the combs, or stands stationary upon them, but whether moving or standing never ceases flapping her wings. The noise thus produced, a sort of buzzing, seems to be a call understood by the populace within hearing, for three or four of them immediately approach and surround her. They begin to aid her to disembarrass herself of her load, each taking and swallowing more or less of her ambrosia until the whole is disposed of.

* Darwin's Loves of the Plants.

156. When more pollen has been collected than the society wants for present use, it is stored up in some of the unoccupied cells. The bee, laden with it, puts her two hind legs into the cell, and with the intermediate pair pushes off the pellets. When this is done she, or another bee if she be too much fatigued, enters the cell head-foremost and remains there for some time, during which she is occupied in diluting, kneading, and packing the bee-bread; and so they proceed one after another, until the cell has been well packed and filled with the store of provisions. In some combs a large portion of the cells is filled with this ambrosia, in others, cells containing it are intermixed with those filled with honey or with bread. It is thus everywhere at hand for use.*

The propolis, the third object of bee industry, is collected from various trees, and especially from certain species of the poplar. It is soft and red, will allow of being drawn out into a thread, is aromatic, and imparts a gold-colour to white polished metals. It is employed in the hive, as already stated, not only in finishing the combs, but also in stopping up every chink and orifice by which cold, wet, or any enemy could enter. They coat with it the chief part of the inner surface of the hive, including that of the sticks placed there for the support of the comb. It is carried by the bees in the same manner as is the pollen on the hind legs.

157. The radius around their habitation, within which the bee industry is confined, is differently estimated, being according to some a mile, and according to others extending to a mile and a half. Various experiments prove that it is by their scent that the bees are guided to the localities where their favourite flowers abound.

* Kirby, Int., ii. 151.

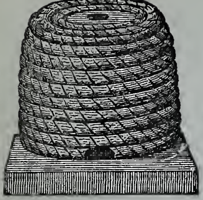


Fig. 63.—Scotch hive.

Fig. 64.—Radouan's hive.

Fig. 65.—Cork hive (South of France).

THE BEE.

CHAPTER VI.

158. How they fly straight back to the hive—manner of discovering the nests of wild bees in New England.—159. Average number of daily excursions.—160. Bee pasturage—transported to follow it—in Egypt and Greece.—161. Neatness of the bee.—162. Its enemies.—163. Death's-head moth.—164. Measures of defence adopted by Huber.—165. Measures adopted by the bees.—166. Wars between different hives.—167. Demolition of the defensive works when not needed.—168. Senses of insects.—169. Senses of the bee.—170. Smell.—171. Experiments of Huber.—172. Remarkable tenacity of memory.—173. Experiments to ascertain the organ of smell.—174. Repugnancy of the bee for its own poison.—175. Their method of ventilating the hive.—176. Their antipathy against certain persons.—177. Against red and black-haired persons.—178. Difference of opinion as to the functions of the antennæ.—179. Organs of taste.—180. Hearing: curious anecdotes.—181. Vision.—182. Peculiar characters of queens; royal old maid.—183. Drone-bearing queens.—184. Change of their instincts and manners.—185. Their treatment by the workers.—186. Nuptials never celebrated in the hive.—187. Effect of amputating the royal antennæ.

158. One of the many wonders presented by their economy is the directness and unerring certainty of their flight. While collecting their sweets they fly hither and thither, forward or backward, and right or left, as this or that blossom attracts them; but when fully laden with the spoil, though upwards of a mile from their city, they start for it in a course more exact than if they were guided

by a rudder and compass, governed by the hand of the most consummate navigator. By what means this is accomplished has never been explained, but connected with it is an account given in the "Philosophical Transactions" which we cannot refrain from quoting here. "In New England a species of wild hive-bees abounded in the forests about the year 1720. The following was the method practised for discovering their nests and obtaining their honey. The honey-hunters set a plate containing honey or sugar, upon the ground on a clear day. The bees soon discovered and attacked it. Having captured two or three who had thus gorged themselves, the hunter liberated one of them and marked the direction in which it flew. He then changed his position, walking in a direction at right angles to the course of the bee to a distance of a few hundred feet, where he liberated another of his little captives, and noted as before the direction of its flight. The point where the two directions thus obtained, intersected, was of course that to which both bees had directed their course, and there the nest was always found."

159. The industry of the bee may be estimated by the average number of its daily excursions from the hive to collect provisions. According to Reaumur, if the total number of excursions be divided by the total number of bees in a hive, the average number daily made by each bee would be from five to six. But as one-half of the bees are occupied exclusively with the domestic business of the society, either in nursing and tending the young, packing and storing the provisions, or constructing the combs, the total number of excursions must be divided, not between the whole, but between only half the total number of bees, which would give ten excursions to each individual of the collecting class; and if the average length of each excursion be taken at three quarters of a mile, this would give the average distance travelled by each collector as fifteen miles! It is estimated by Kirby that the quantity of ponderable matter thus transported during a season in a single hive would be about 100 lbs. "What a wonderful idea does this give of the industry and activity of those useful little creatures! and what a lesson do they read to the members of societies, that have both reason and religion to guide their exertions for the common good! Adorable is that Great Being who has gifted them with instincts which render them as instructive to us, if we will condescend to listen to them, as they are profitable." *

160. The plants and flowers which form the pasturage of the bees are, in many countries, produced at different places at different seasons of the year; and where the bees in a particular neigh-

* Kirby, Int., ii. 155.

bourhood are numerous, the pasturage surrounding their hives often becomes exhausted. In such cases the agriculturists transport the bees from localities which they have exhausted, to others in a state of comparative abundance, just as the shepherd drives his sheep from field to field, according as the pasturage is eaten down. In Egypt, towards the end of October, when the inundations of the Nile have ceased, and the husbandmen can sow the land, saintfoin is one of the first things sown; and as Upper is warmer than Lower Egypt, the saintfoin gets there first into flower. At this time bee-hives are transported in boats from all parts of Egypt into the upper district, and are there heaped in pyramids upon the boats prepared to receive them, each being marked with a number which indicates its owner. In this station they remain for some days, and when it is considered that they have pretty well exhausted the surrounding fields of their sweets, they are removed a few leagues lower down, where they are retained for a like interval; and so they descend the river, until towards the middle of February they arrive at its mouth, where they are distributed among their respective proprietors.*

A similar practice prevails in various parts of the East and in Greece. The inhabitants of the towns are often the proprietors of fifty or sixty hives, the product of which forms an article of their trade. The hives are sent in the season when the herbage is in flower to the various rural districts, being sealed up by the owner, the small bee-door only being open, and are given in charge to the villagers, who at the close of the season are paid for their care of them. Ranges, consisting of five or six hundred hives, are often seen thus put out to grass.†

161. Bees are remarkable for neatness and cleanliness, both as to their habitations and their persons. They remove all dirt and nuisances from their hive, with the regularity of the neatest housewives. When their strength is insufficient for this, they contrive various ingenious expedients to abate the nuisance. If snails find their way into the hive, as they sometimes do, they kill them with their stings; and in order to prevent noisome and unwholesome effluvia from their decomposing remains, they embalm them with propolis. If the snail is protected from their stings by its shell, they bury it alive in a mass of propolis.

When pressed by natural wants, they do not defile their habitation by relieving themselves in it, but go abroad for the purpose.

When a young bee issues from the cell, a worker immediately approaches, and, taking out its envelope, carries it out of the hive; another removes the exuviæ of the larva, and a third any

* Reaumur, v. 698.

† Willock, in "Gardeners' Chronicle, 1841, p. 84.

filth or ordure that may remain, or any pieces of wax that may have fallen in when the young bee broke through its cocoon. But they never attempt to remove the silk lining of the cell spun by the larva in its first transformation, because that, instead of being a nuisance, gives increased solidity and ornament to the cell.

162. Notwithstanding the amiable character and excellent political organisation of the bees, these little people have numerous enemies, with some of whom they are often compelled to wage offensive wars, and against others to fortify themselves, by expedients and with skill, which will bear comparison with the operations of the most consummate military engineers. Sebastopol itself was not more ingeniously defended by its outworks than, in certain cases, bee-hives are.

From the curious account which Latreille has given us of *Philanthus aviporus*, a wasp-like insect, it appears that great havoc is made by it of the unsuspecting workers, which it seizes while intent upon their daily labours, and carries off to feed its young.

163. Another insect, which one would not have suspected of marauding propensities, must here be introduced. Kuhn informs us, that long ago (in 1799) some monks who kept bees, observing that they made an unusual noise, lifted up the hive, when an animal flew out, which, to their great surprise, no doubt, for they at first took it for a bat, proved to be the death's-head hawk-moth (*Acherontia atropos*), already celebrated as the innocent cause of alarm; and he remembers that several, some years before, had been found dead in the bee-houses. M. Huber also, in 1804, discovered that it had made its way into his hives and those of his vicinity, and had robbed them of their honey. In Africa, we are told, it has the same propensity; which the Hottentots observing, in order to monopolise the honey of the wild bees, have persuaded the colonists that it inflicts a mortal wound.

This moth has the faculty of emitting a remarkable sound, which he supposes may produce an effect upon the bees of a hive, somewhat similar to that caused by the voice of their queen, which as soon as uttered strikes them motionless, and thus it may be enabled to commit with impunity such devastation in the midst of myriads of armed bands.

The larvæ of two species of moth (*Galleria cereana* and *Mellonella*) exhibit equal hardihood with equal impunity. They, indeed, pass the whole of their initiatory state in the midst of combs. Yet, in spite of the sting of the bees of a whole republic, they continue their depredations unmolested, sheltering themselves in tubes made of grains of wax, and lined with silken tapestry, spun and woven by themselves, which the bees (however disposed they may be to revenge the mischief which they do to them, by devouring what to all other animals would be indigestible—their wax) are unable to penetrate. These larvæ are sometimes so numerous in a hive, and commit such extensive ravages, as to force the poor bees to desert it and seek another habitation." *

164. Huber gives the following most interesting account of the measures taken by his bees, to fortify themselves against the incursions of the death's-head moth.

When he found his hives attacked and their store of honey pillaged by these depredators, he contracted the opening left for the exit and entrance of the bees to such an extent, as while it allowed them free ingress and egress, it was so small that their plunderers could not pass through it. This was found to be perfectly effectual, and all pillage was thenceforward discontinued in the hives thus protected.

165. But it happened that in some of the hives this precaution was not adopted, and here the most wonderful proceeding on the part of the bees took place. Human contrivance was brought into immediate juxtaposition with apiarian ingenuity.

The bees of the undefended hives raised a wall across the gate of their city, consisting of a stiff cement made of wax and propolis mixed in a certain proportion. This wall, sometimes carried directly across and sometimes a little behind the door, first completely closed up the entrance; but they pierced in it some openings just large enough to allow two bees to pass each other in their exits and entrances.

The little engineers did not follow one invariable plan in these defensive works, but modified them according to circumstances. In some cases a single wall, having small wickets worked through it at certain points, was constructed. In others several walls were erected one within the other, placed parallel to each other, with trenches between them wide enough to allow two bees to pass each other. In each of these parallel walls several openings or wickets were pierced, but so placed as not to correspond in position, so that in entering a bee would have to follow a zigzag course in passing from wicket to wicket. In some cases these walls or curtains were wrought into a series of arcades, but so that the intervening columns of one corresponded to the arcades of the other.

The bees never constructed these works of defence without urgent necessity. Thus, in seasons or in localities where the death's-head moth did not prevail, no such expedients were resorted to. Nor were they used against enemies which were open to attack by their sting. The bee, therefore, understands

* Kirby, vol. i. p. 130.

not merely the art of offensive war, and can play the part of the common soldier, but is also a consummate military engineer; and it is not against the death's-head moth alone that it shows itself capable of erecting such defences.

166. Thinly peopled hives are sometimes attacked by the population of other bee cities. In such cases, incapable of immediate defence by reason of their inferior numbers, they erect similar fortifications, but in this case they make the wickets in the walls so small that a single worker only can pass through them; and a small number stationed on the inside of these openings, are accordingly sufficient to defend the hive against the attack of large besieging armies.

167. But when the season for swarming arrived, these works of defence, whether constructed against the invasion of the moth or hostile bees, became an impracticable obstruction to the exit of the succession of emigrating colonies, and were therefore demolished, and were not reconstructed without pressing necessity. Thus the works constructed in 1804 against the invasions of the moth were taken down in the swarming season of 1805; and as the plunderers did not re-appear in that year, they were not re-erected. But in the autumn of 1807, the moths appearing in great numbers, the bees immediately erected strong barricades, and thus effectually prevented the disaster with which their population was menaced. In the next swarming season, in May 1808, these works were again demolished.

It ought to be observed, that whenever the door of the hive is itself too small to admit the moth, the bees erect no defences against it.*

168. One of the most interesting and, at the same time, most difficult question connected with the faculties of insects, is that of the number and nature of their senses. It has been often and truly said, that no being, however intelligent, can form even the most obscure notion of a sense of which he is himself deprived. The man deprived of sight, to whom the colour scarlet was elaborately described, said that his notion of it was that of the sound of a trumpet. Granting then the possibility that insects may be endowed with a peculiar sense, or mode of perception, of which we are destitute, we are in no condition to form a conception of the power or impressions of such a sense, any more than the blind man was who attempted to acquire a conception of a red colour.

But without supposing the possible existence of peculiar senses independent of the five with which we are endowed, it may be that the very organs which we possess may be given with an infi-

* Huber, ii. 293—298.

nitely higher degree of sensibility to these minute species. Their auditory organs may be such as to give them the power of ear-trumpets, and their eyes may be either microscopic or telescopic, or both united. Their olfactory organs may have a susceptibility infinitely more exalted than ours, as indeed innumerable facts prove those of many species of inferior animals to be. Art and science have supplied us with numerous tests, by which the physical properties of substances are distinguished, by characters which escape all our senses. Why may not the Creator have given to inferior animals specific organs, capable of perceiving those distinctions, as surely and promptly as the eye distinguishes shades of colour, the nose varieties of odour, or the ear the pitch of a musical note?

169. Among social insects, the hive-bee stands preeminent for the manifestation of sensitive faculties. Sight, touch, smell, and taste, are universally accorded to it. Hearing was regarded as doubtful, but we have shown that a noise produced at any side of a hive, will immediately bring there the queen and her court, to see what is the matter.

But if the sensibility of the ear be doubted, what exaltation of power do we not find in the eye! How unerring is the perception of her dwelling, while the bee lies at distances and under circumstances, which might well appear to baffle the most acute human organ, aided even by human intelligence! The little bee, issuing from her hive, departs upon her industrial excursion, and flies straight to the field which she has already discovered to be most fertile of honey flowers. Her route to it is as straight as the flight of a bullet from a gun to the object aimed at. When she has gathered her load, she rises in the air, and, flying back to her hive with the same unerring certainty, finds it among many, and entering it, finds the cells which are appropriated to her care.

The sense of touch is, perhaps, even more to be admired than that of sight, for it supplies the place of that sense in the darkness of the internal labyrinth of the hive. In darkness the architecture of the combs is constructed, the honey is stored in the cells appropriated to it, the young are nourished, their food being varied with their respective ages, the queen is recognised,—and all this appears to be accomplished by some sensitive power possessed by the antennæ, organs whose structure, nevertheless, seems to be incomparably inferior to that of the human hands.

The industrial activity of the bee is much less excited by warm weather and bright sunshine, than by the prospect of collecting an abundant supply of provisions for the hive. When the lindens and the buck-wheat are in flower, they brave the rain and cold, commencing their excursions before sunrise, and continuing their work much later than their customary hours. But when the flowers rich in pollen and nectar prevail in less abundance, and when the scythe has swept away the flowers which enamelled the fields, even the brightest sunshine and the warmest days fail to attract the industrious population to go abroad.

170. Of all the senses of the bee, that of smell appears to be the most acute. Certain odours have an irresistible attraction for the insect, while others are in the same degree repugnant to it. Of the former, as might naturally be expected, honey is by far the most exciting. It was supposed by Huber, not without much probability, that the bee is attracted to this or that flower, not by its colour, form, or other visible properties, but by the odour of the nectar it contains. To test this experimentally, Huber put some honey in a box, so as to be invisible from the outside, and placing it in the neighbourhood of his hives, found that the bees crowded round it in a few minutes, finding their way to the honey through a small hole left for the purpose.

171. He next made several small entrance holes in a box containing honey, but covered each hole with a sort of card valve, such that it would be possible for a bee to raise it and enter the box. The box thus prepared was placed at two hundred yards from the hives. In half an hour the bees found it, crowded in great numbers on every side of it, examining carefully every part, as if to seek for an entrance. At length, finding the valves, they set to work at them, and never ceased until they succeeded in raising them, when they entered and took possession of the spoil.

How exquisitely acute must be their olfactory organs will be apparent, when it is considered that, in this case, the box and valves must have confined very nearly the whole effluvia of the honey.

172. The following remarkable proof of the tenacity of memory with which the bee is endowed, is given by Huber. A supply of honey had been placed in autumn upon an open window. The bees had the habit of coming to feast upon it. This honey being removed, the window was closed, and remained closed during the winter. In the following spring the bees again found their way to the same window, expecting again to find a supply there, although none had been placed there. It is evident in this case, that the insect must have been guided by its memory alone, and that it was capable of retaining a recollection of places and circumstances for several months.

173. Huber made several curious and interesting experiments to determine the seat of the sense of smell. If, as was natural to expect, it were situate in some of the appendages of the mouth,

it would be deadened by stopping these, as we defend ourselves from a noisome odour by stopping the nose. Catching several bees he, therefore, held them while he stopped their mouths and probosces with flour-paste, and liberating them when the paste was hardened, he found that they no longer showed any sign of the possession of a sense of smell. They were neither attracted by honey, nor repelled by objects whose odours were known to be most repugnant to them.

174. Among the substances to whose odour the bee shows the strongest repugnance, is its own poison. This was demonstrated by Huber by very remarkable experiments. Having provoked the insect to put forth its sting, and eject its poison, he presented this offensive juice on the end of a sharp instrument to some worker bees, which were quietly resting at the door of their hive. A general agitation was immediately manifested among them. Some launched themselves on the poisoned instrument, and others fell upon the individual who held it. That it was not the instrument itself which in this case provoked their rage, was proved by the fact, that a similar one, bearing no poison, being presented to them, did not produce any effect.

175. An inconvenient elevation of temperature and want of ventilation will sometimes impel the bees to leave their combs, but if they are excited to remain upon them by the want of feeding, they know how to reconcile the conflicting impulses. In that case they produce coolness and change of air without deserting the provisions which surround them, or the care of their young. A certain number of the insects begin to flap their wings, which are thus used as fans, producing currents of air. But as they are not able to sustain this labour for an indefinite time, they take it by turns, regularly relieving each other.

To try what the conduct of the bees would be, if by artificial means the ventilation of the hive were so impeded that the usual small number of *fanners* would not suffice, Huber submitted hives to such unusual conditions, and found that in such cases the number of bees flapping their wings was augmented in the same proportion as the ventilation was impeded, until at length the whole population of the hive were thus occupied.

176. The antipathy which bees manifest against particular individuals, is generally ascribed to some odour proceeding from their persons to which the insect bears a repugnance. M. de Hafor, of the Grand Duchy of Baden, had been for many years an assiduous cultivator and amateur of bees, and was on such friendly terms with them that he could at all times approach them with impunity. He would, for example, put his fingers among them, select the queen, and taking hold of her, place her on the palm of his

hand. It happened that this gentleman was attacked with a violent and malignant fever, which long confined him to his bed and his house. Upon his recovery he, naturally enough, revisited his old friends the bees, and began to caress them and renew his former familiarity.

He found, however, to his surprise and disappointment, that he was no longer in possession of their favour, and instead of being received as formerly, his advances were resented as an unwelcome and irksome intrusion; nor was he ever afterwards able to perform any of the usual operations upon them, or to approach them without exciting their rage.

177. According to Dr. Bevan and M. Feburier, both close and accurate observers of the habits of the insect, red and black-haired persons are peculiarly obnoxious to it. Feburier mentions a mastiff to which his bees had a particular aversion, pursuing him into the house with such pertinacity, that doors and windows were obliged to be closed for his protection.

Dr. Bevan mentions that he had two friends, brothers, one of whom was so inoffensive to the bees, that he could stand with impunity over the hive and watch all their doings, while the other could scarcely enter the garden with impunity.

178. The antennæ are generally regarded as the proper organs of the tactile sense, and hence are popularly, though not properly, called feelers,—the feelers being in fact the palpi already mentioned. Naturalists are not agreed as to the functions of the antennæ, though all concur as to their importance. Some consider them as organs of smell, others as organs of hearing; while others claim for them the place of organs of a sixth sense, of which man and the higher animals are destitute. This sense is considered by Kirby as an intermediate faculty between sight and hearing, rendering the insect sensible of the slightest movement of the circumambient air. Dr. Evans, as quoted by Dr. Bevan, in reference to the faculty conferred on the bee by the antennæ, says,—

> "The same keen horns, within the dark abode,
> Trace for the sightless throng a ready road;
> While all the mazy threads of touch convey
> That inward to the mind, a semblant day."

The antennæ, and the two pair of palpi, would seem to have correlative and complementary functions: they are both in constant motion. The palpi are in reality the feelers, in the proper sense of the term; as is apparent by observing the manner in which the insect applies them to the food before eating it.

179. Cuvier considers the organs of taste in the bee to constitute one of its most important characters. The sensibility of these

organs is manifested by the delicate choice of food which the insect makes, showing a preference for those flowers, wherever they can be found, which yield the finest honey. Hence the celebrity of the honey of Narbonne, Hymettus, Hybla, and Pontus.

180. Numerous indications show that the bee possesses the sense of hearing. The manner in which they are attracted to any quarter of the hive where an unusual noise is produced, has been already mentioned. Dr. Bevan mentions some curious examples of their power of hearing, and even of the sense they seem to attach to particular vocal sounds. Thus he mentions an old dame of his acquaintance, who was a very fearless operator in the treatment of these insects, and who used to suppress any movement of anger on the part of the bees merely by saying to them, "Ah! would you dare?" A servant of Mr. Knight, the well-known apiarian, used to quell their anger by exclaiming, "Get along, you little fools!"

Some difference of opinion has nevertheless prevailed as to the existence of this sense in insects. The opinion of Linnæus and Bonnet was against it. Many evidences, however, may be adduced in favour of its existence. Thus, one grasshopper will chirp in response to another, and the female will be attracted by the voice of the male. Brunelli shut up a male in a box, and allowed the female her liberty; as soon as the male chirped she flew to him immediately. A bee on the window within a bee-house will make a responsive buzz to its fellows on the outside.*

181. The indications of a keen sense of vision, in the certainty and precision with which the bee flies to its pasturage and back to its hive, have been already mentioned. Naturalists, however, are not agreed as to the particular power of the eyes of these insects. Some, for example, contend that their sight is extremely short, and that

> Its feeble ray scarce spreads
> An inch around;

while others contend that its vision of near objects is obscure and imperfect, but for distant ones quite distinct. Thus Butler and Wildman say that they have observed the bees go up and down seeking the door of the hive, as if they were in the dark; but Bevan observed that they easily discovered it by rising on the wing, and thus throwing themselves at a greater distance from it.

182. Among the mysteries of the social economy of the bee, there is perhaps nothing more curious than the circumstances which, in certain cases, appear to affect the personal character of the

* Bevan, p. 362.

sovereign. We have already explained that there are certain periods in the life of the queen, during which she produces eggs of certain sorts,—at one period those only of workers, at another those only of drones. But if the epoch of her nuptials be postponed to a certain advanced period of life, at which, if we may be allowed the expression, she begins to approach the condition of an *old maid*, a singular change is found to have taken place in her constitution, in consequence of which she is no longer capable of having any but *male offspring*, in other words, she is incapable of laying any but drone eggs.

183. Now since such a queen is obviously incapable of discharging those functions, which are indispensable to the continuance of the population over which she presides, and of whose young she ought, in the ordinary course of nature, to be common mother, it might be inferred that the instincts of the insects would lead them to disembarrass themselves of a sovereign, incapable of discharging the most important functions of her office, and to substitute for her, as we know they always have the power to do, one who should enjoy the plenitude of these functions.

184. Among the innumerable experiments of Huber, those are not least interesting which were directed to this point, that is to say, to submit the faculties of the queen to tests supplied by artificial means, contrived for placing her in social conditions, in which it could scarcely ever happen that she should find herself in the common course of *bee-nature*.

The first question which suggested itself to the great naturalist, was to ascertain whether queens, who thus married so late in life as to have only drone offspring, would exhibit the same spirit of jealous hostility towards the tenants of royal cells, and the future aspirants to thrones, as is invariably manifested by younger royal brides. To determine this it was necessary to place such a queen in a queenless hive, in which, however, there was at least one royal cell tenanted by a princess. Huber, therefore, placed the queen, who had not married until she had bordered upon old maidenhood, in a hive which had no queen, but in which there was one royal cell occupied by a princess. The old bride, whose nuptials had not been celebrated until she had attained the twenty-eighth day of her age, laid nothing of course except drone eggs. On being placed in the hive she exhibited none of the usual signs of hostility against the royal cell. On the contrary, she passed and repassed it many times a day without seeming to take the least notice of it, or to distinguish it in any way from the numerous cells which surrounded it on every side. In such of these latter cells as were unoccupied she deposited eggs, and notwithstanding the jealous guard which the workers kept around the royal cell occupied by the princess, the queen did not appear either to show a disposition to attack the imprisoned princess, or to fear any attack on the part of the latter.

185. Meanwhile the workers exhibited towards the queen the same respect and homage, lavished upon her the same affectionate cares, offered her honey, and formed round her in the same respectful circle, as they are wont to do round a sovereign possessing all the functions necessary to perpetuate the race.

It appears, therefore, that the postponement of the royal nuptials beyond a certain age, while it deprives the queen of the faculty of having any but male offspring, also deprives her of that instinctive feeling of jealous hostility towards rival queens, which forms a trait so remarkable in the characters of queens, whose nuptials take place at an earlier and more natural age.

To those who regard these little creatures as mere pieces of mechanism, obeying unreflecting impulses, having purposes always directed to the fulfilment of some important end in their economy, it will doubtless be surprising that members of the community so useless as those princesses, who postpone their nuptials until they are incapable of bearing worthier offspring, should not be destroyed as the drones are, after they cease to be useful. So contrary to this, however, is the fact, that no royal bride, however young, is the object of solicitude more tender, affection more sincere, and homage more profound, than those drone-bearing mothers. "I have seen," says Huber, "the workers lavish the most tender care upon such a queen, and, after her decease, surround her inanimate body with the same respect and homage as they had paid to herself while living, and, in the presence of these beloved remains, refuse all attention to young and fertile queens who were offered to them." * It must be admitted that this looks much more like the tenderness of moral affection than the mechanical impression of blind instinct.

186. We have already stated that the royal nuptials are always celebrated in the air, and under the bright beams of the sun, where the bride rises with her numerous suitors, and makes her choice. This bridal excursion into the fields of ether is so intimately interwoven with the customs of these little people, that if, by cutting off her wings before her nuptials, her majesty is deprived of the power of flight, she is consigned irretrievably to a life of single blessedness, since she can never submit to nuptials celebrated in the recesses of the hive, instead of the gay and bright sunshine of the free air.

* It will be observed that, according to the general habit of the blind, Huber uses the language of vision, and describes what he saw with the eyes of Bernens as if he had seen them with his own.

Lest it might be imagined, as indeed Swammerdam supposed, that the marriage is really consummated in this case in the hive, and that her majesty is only rendered sterile by the mutilation she has undergone, Huber cut off the wings of a queen immediately after the royal nuptials, but before her majesty had yet any offspring. In this case, however, her fertility was as great as usual, and she produced the customary number and variety of eggs.

187. One of the questions in insect physiology, which has been attended with a certain degree of doubt, is that which regards the functions of the antennæ. Huber, therefore, desiring to ascertain how the queen would be affected by the privation of these organs, cut off first one and then both, observing the conduct of her majesty after such mutilation.

The excision of one only of the antennæ produced no discoverable effect upon her faculties or conduct, but the amputation of both was followed by some very remarkable consequences.

The antennæ of a queen of limited fertility, who was incapable of having other than drone offspring, were cut off. From the moment she lost these organs she appeared to be affected by a sort of delirious intoxication. She ran over the combs with extraordinary vivacity. She did not give her suite, who formed the usual circle around her, time to make way for her, but rushed madly through them, violently breaking their ranks. She did not deposit her eggs in cells, but dropped them at hazard. The hive not being very full, there were parts of it unoccupied by combs. To these parts she rushed, and remained there a considerable time quiescent, appearing to avoid the presence of her subjects. Some of them, nevertheless, followed her to these deserted places, and eagerly testified their solicitude for her, caressing her, and offering her honey. This she generally declined; and when now and then she seemed disposed reluctantly to accept it, she appeared to lose the power of presenting her proboscis to receive it, directing that organ at one time to the head and at another to the legs of the workers, so that it was only by chance it encountered their mouths. She would then run back to the combs, and from the combs to the glazed sides of the hive, in wild delirium, never ceasing to drop her eggs here and there as she went along.

At other moments she seemed to be tormented with a desire tc quit the hive, and rushed to the door for that purpose, but the orifice being too small to allow her body to pass through it, she was forced to desist, and returned to the interior. Notwithstanding this state of delirium, the bees never ceased to lavish upon her those cares which they are accustomed to bestow on their queen; but she received them with indifference.

Whether all this singularity and eccentricity of conduct was to be ascribed to the excision of the antennæ, or to that mutilation combined with the partial sterility which limited her offspring to drones, was not clear. To decide this point, Huber amputated the antennæ of a perfect queen, married at an early age, and who was bearing a numerous offspring, consisting of workers, drones, and princesses. This queen he placed in the same hive with the former, with a view to determine at once two questions, the one relating to the general conduct of the amputated queen, and the other, that which regarded the mutual bearing of two mutilated personages.

The general conduct was the same as that of the former queen. There was the same wild delirium; the same rushing here and there as if under the influence of intoxication; the same efforts to escape from the hive; and, in a word, the same peculiarity of conduct and manners. A like difference was apparent in their conduct towards each other. Instead of entering into deadly combat, as queens in their natural state would have done in like circumstances, they met and passed each other again and again without the slightest indication of mutual hostility. This is perhaps the strongest proof which can be obtained, that the privation of the antennæ utterly subverted their natural instincts.

Another curious social anomaly was manifested on this occasion. It will be recollected that where a strange queen is introduced into a hive over which a regular sovereign already presides, the population surround her, confine her as a prisoner within a ring of sentinels, and refuse to permit her to enter their city. In the present case, no such measures were adopted. On the contrary, the second mutilated queen was received with the same signs of welcome, and immediately became the same object of attention and homage as the first.

But the most wonderful fact of all those developed in this series of experiments, was that when a third queen in the perfect state, without mutilation, was introduced, the bees who had already treated the other two so well, immediately proceeded to maltreat this third and perfect queen. They seized her, dragged her about, bit her, and so closely surrounded her as to leave her room neither to move nor to breathe.

Having observed the apparent desire of these mutilated queens to issue from the hive, which they were only prevented from doing by the limited magnitude of the door, and desiring to see whether the bees or any considerable number of them would depart with her, as they would do with a perfect queen, Huber, after taking away the two queens who were sterile, or partially so, and leaving her who was fruitful in all respects, but deprived of her antennæ, he enlarged the door so as to allow her free passage through it. So soon as this was done, she went out, and took flight, but not a single bee accompanied her. She was, moreover, so heavy, being full of eggs, that she was not able long to sustain herself on the wing, and fell to the ground.

Various conjectures are made by Huber to explain this singular departure from the prevailing habits of the insect, but none of them appear so satisfactory as to require to be reproduced.

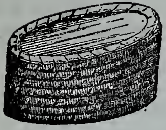


Fig. 85.—Oblique piece to elevate a village hive.

Fig. 86.—The bee-dress.

THE BEE.

CHAPTER VII.

188. Apiculture.—189. Suitable localities and pasturage.—190. The Apiary.—191. Out-door Apiary.—192. Bee-house.—193. Cabinet bee-houses.—194. Form and material of hives.—195. Village hive.—196. English hive.—197. Various forms of hives.—198. Various forms of bee-boxes.—199. Bee-dress and other accessories of apiculture.—200. Purchase of hives.—201. Honey harvest.—202. Honey and wax important articles of commerce.—203. Various sorts of wild honey.—204. Periodical migration of bees.—205. Poisoned honey.—206. Maladies of bees.—207. Curious case of abortive brood.—208. Superstition of bee cultivators.—209. Enemies of bees.—210. Attacks of bees when provoked.—211. Anecdote of Mungo Park.—212. Anecdote of Thorley.—213. Bee wars.—214. Curious case of a battle.

188. Apiculture is the name given to the art by which the products of the industry of the bee are augmented in quantity, improved in quality, and rendered subservient to the uses of man.

189. The most favourable localities for the practice of apiculture are of course those of which the climate is suitable to the habits and character of the insect, and which most abound in those vegetable productions on which it loves to feed. Among these the principal are saintfoin, Dutch clover (*trifolium repens*), buckwheat, rape, honeysuckle, clover (*trifolium pratense*), and yellow trefoil (*medicago lupulina*). According to Dr. Bevan, the earliest

resources of the bee are, however, the *willow*, *hazel*, *osier*, *poplar*, *sycamore*, and *plane;* to which may be added, the *snow-drop*, *crocus*, *white alyssum*, *laurustinus*, *orange* and *lemon trees*, *gooseberry* and *currant* and *raspberry bushes*, *sweet marjoram*, *winter-savory*, *thyme*, and *mint*. In a word, fruit-trees and green-house plants and shrubs in general, such especially as abound in ornamental grounds, all constitute a part of bee-pasturage.

"First the gray willows' glossy pearls they steal,
Or rob the hazel of its golden meal;
While the gay crocus and the violet blue
Yield to the flexile trunk ambrosial dew.

EVANS, *quoted by* BEVAN.

An undulating country is highly favourable to the bee.

190. The apiary should be near the dwelling-house, in the garden, and in a position sheltered from unfavourable winds. The farm and poultry-yard should be avoided, as well as too great proximity to railways, forges, factories, bakehouses, workshops, and the like. The bee loves tranquil spots, planted with ornamental shrubs and fruit-trees, and sown with sweet flowers, such as mignonette, thyme, mint, rosemary, &c. The aspect of the apiary may be east, west, or south, according as the one or other affords best shelter, but never north.

191. The hives should be placed on separate stands, a few feet apart, should be clear of any wall or fence, and elevated eighteen inches or two feet above the ground.

Hives are sometimes assembled together in the open air, forming an out-door apiary, such as is shown in fig. 54, p.1, in which case they are generally made of straw, and protected in cold weather by straw roofs, but sometimes also formed of wooden boxes, as shown in the figure.

This arrangement, having the advantage of simplicity and cheapness, is most commonly adopted, especially by those to whom economy is important, and in warm climates where shelter is less necessary.

192. Under other circumstances bee-houses are much more strongly recommended, as well for comfort and convenience as for security. The bee-house, one form of which is shown in fig. 55, p. 33, consists of two or more rows of shelves, established one above the other, on which the hives are placed at distances of from twelve to eighteen inches apart, so that the bee-doors shall be from two to three feet asunder. The house should be thatched not only on the roof but on the sides and ends. A passage should be provided for approaching the hives behind, and windows in the side for ventilation.

193. A form called the Cabinet bee-house is shown in fig. 56,

p. 65, where B B are doors, one of which is glazed, and A a pipe of tin or caoutchouc, by which the bees have ingress and egress.

194. Hives have been constructed of different materials, as straw, osiers, rushes, sedges, wood, and earthenware; and of still more various forms, some being bell-shaped or conical, some cylindrical, some square in their section, some with rectangular and some with oblique tops, being internally divided by comb-frames fixed or movable, by shelves, and other expedients.

Their forms of structure depend in some degree upon the object of the proprietors. When apiculture is prosecuted on a large scale for the produce of honey and wax, as articles of trade, the foreign cultivators prefer hives of the most simple forms and most easy construction, and those from which the products can be obtained with most facility. The material preferred is, generally, straw or rushes. The process of making such a hive is indicated in fig. 57.

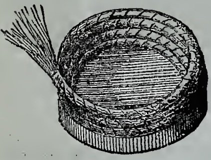


Fig. 57.—Process of making a straw hive.

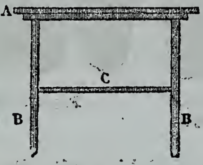


Fig. 61.—Movable comb-frame of the village hive.

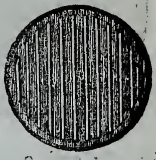


Fig. 59.—Top of the cylindrical body of the village hive.

195. The bell-shaped straw hive, called the village hive, represented on the right of fig. 58, p. 49, is cylindrical in the body, and surmounted by a bell-shaped cap. The top of the cylindrical body is covered by a frame of bars, shown separately in fig. 59 and the cap itself is shown in fig. 60.

Fig. 60.—Cap of the village hive.

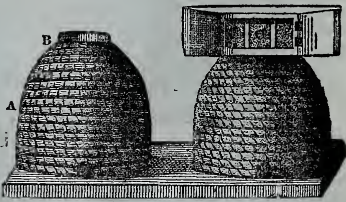


Fig. 62.—Dewhurst's hive.

One of the movable comb-frames is shown in fig. 61, where A is the vertical section of the stage, shown by plan in fig. 59; B the uprights, and C a shelf shown in vertical section.

196. The English hive of Dewhurst, having a box at the top, is shown in fig. 62; where A is the body of the hive, B the opening at the top, and C the box provided with shutters.

197. In fig. 63, p. 81, is shown a form of straw hive used in Scotland, and in fig. 64 the Radouan hive, similar in form to the village hive, but provided with movable pieces, by placing which successively below it, its elevation can be gradually augmented without disturbing the superior part, so as to give increased space to the bees and prevent the issue of swarms.

A form of hive much used in the South of France, and known to French apiarists as the Vulgar Hive (Ruche Vulgaire), is shown on the left of fig. 58, p. 49, in the process of transferring the bees from one hive to another.

A form of cork hive used in the South of France is shown in

Fig. 66.—Cylindrical hive (Switzerland and Italy).

Fig. 67.—Della Rocca hive (Greece and Turkey).

fig. 65; and a cylindrical hive with its axis horizontal, much

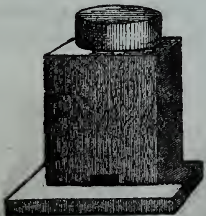


Fig. 68.—Murie's bee-box, with cylindrical cap (French).

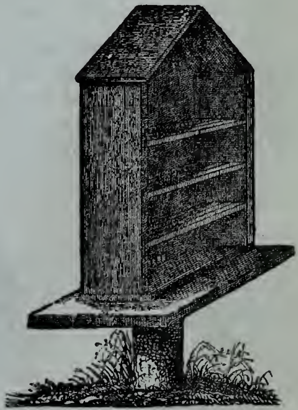


Fig. 69.—De Frarière's garden hive.

used in Switzerland and Italy, is shown in fig. 66.

In Greece and Turkey a hive of earthenware, known as that of della Rocca, is much used, fig. 67.

Straw hives have the advantage over wooden boxes in being better non-conductors of heat, and therefore preventing immoderate cold in winter and immoderate heat in summer in the

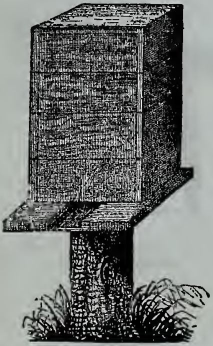


Fig. 70.—Patteau's bee-box, with horizontal divisions.

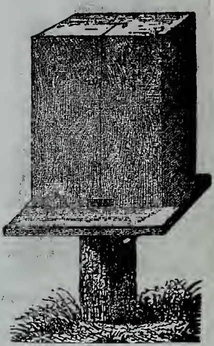


Fig. 71.—Gélieu's bee-box, with vertical division.

interior. They are on this account preferred where the apiary is uncovered.

198. When apiculture is practised partly for the purpose of

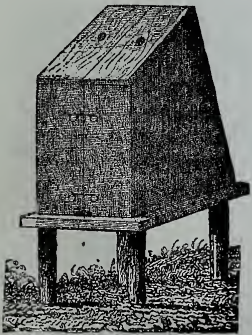


Fig. 72.—Feburier's bee-box, with vertical division and sloping roof.

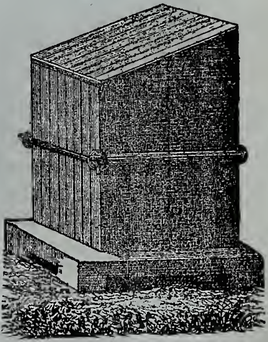


Fig. 73.—Huber's experimental leaf-hive.

observing the habits of the insect, boxes with divisions and movable comb-frames, with glazed openings and other like contrivances, are used. These *bee-boxes*, as they are called, are

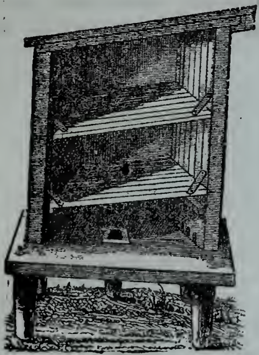


Fig. 74.—Debeauvoy's bee-box, with sloping roof and shelves.

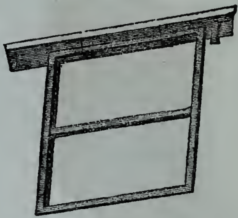


Fig. 75.—Vertical frame of box shown in fig. 74.

infinitely various in form, and although our limits will not allow us to enter into the details of the advantages derived from them

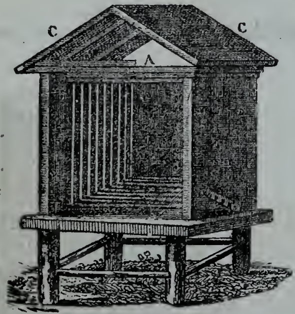


Fig. 77.—Debeauvoy's box, with vertical frames.

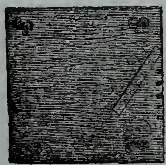


Fig. 78.—Shutter of box shown in fig. 77.

by their inventors and contrivers, it will nevertheless be useful to show the forms of those most generally used.

The common bee-box used in the South of France is shown in fig. 76, p. 17, the cover C being hinged, so as to be capable of being raised at pleasure. The process of transferring the bees

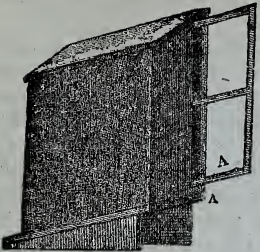


Fig. 78.*—Lefebvre's box, with movable frames. A, a frame drawn out.

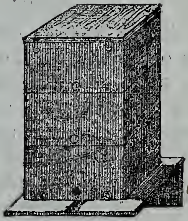


Fig. 79.—Hamet's bee-box, with oblique horizontal divisions.

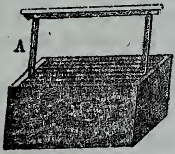


Fig. 80.—One of the divisions by which fig. 79 is elevated, with a movable frame, A, drawn out.

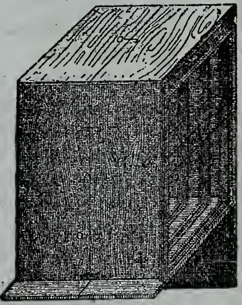


Fig. 81.—Hamet's bee-box, with divisions and movable frames.

from one hive to another by smoking them, is indicated, and also the method of hiving a swarm.

Fig. 82.—Uprights of fig. 81.

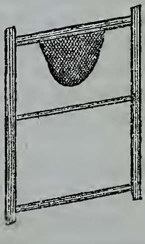


Fig. 83.—Frame of fig. 81.

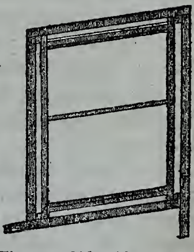


Fig. 84.—Side of fig. 81, with its movable frame.

199. In the practical details of apiculture there are many

accessories, some of which are of occasional, and others of constant use.

The *bee-dress*, fig. 86, is a sort of armour, by which the operator is protected from all hostile attacks of the insect. It is usually made of Scotch gauze, or catgut, and so formed as to inclose the head, neck, and shoulders, as shown in fig. 76, p. 17, where a person invested with such a dress is represented in the act of hiving a swarm. It should have long sleeves to tie round the wrists over a pair of thick gloves, and the body should descend low enough to be tied round the waist. Thick woollen stockings and a woollen apron are recommended, the material being one from which the bee can readily withdraw its sting.

Fig. 87.

Fig. 88.

Knives of different forms (figs. 87, 88) should be provided, for the partial removal of the honey-combs, when the smothering process is not resorted to.

A bellows connected with a fumigator (fig. 89) for projecting tobacco-smoke into those parts of the combs from which it is desired to expel the bees, should be provided.

A hive with a handle for mixing swarms is often useful (fig. 90).

A basket, with an open bottom, placed over a tub for the purpose of draining the honey-combs, is also a convenient accessory (fig. 91).

200. A hive should, in general, be purchased in autumn, and its value will be pretty well ascertained by its weight. That of a good hive which will be sure to go through the winter, and to be productive in the ensuing season, should be from 25 to 30 lbs., and should contain about a peck of bees. If the weight be much greater than 30 lbs., a part of the honey may be advantageously taken out. Hives are to be preferred which are only a year old, and which have sent out no more than a single swarm. Such will be distinguished by the superior whiteness and purity of the combs. The transport should be made in cool weather, and should be conducted without shocks or jolts.

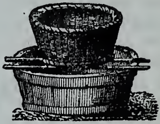
201. Honey should never be taken from any but the nearest and most populous hives. If they are provided with movable comb-frames, it is usual to make a partial harvest in May, the principal stores of the insect being collected between the middle of May and the end of June, the commencement and termination, however, varying three or four weeks, according to the climate peculiar to the locality.

Dr. Bevan recommends, as a general rule, that no honey should be taken from a colony the first year of its being planted.

Fig. 89.

Fig. 90.

Fig. 91.



To make a partial collection of honey, the hive is opened at the top or at the side, and the bees expelled from the combs by puffing tobacco-smoke upon them. The combs are then cut away with knives of suitable forms (figs. 87, 88). This operation requires to be performed with skill and care, so as to avoid as much as possible irritating the bees. To withdraw the queen from the part of the combs which are to be removed, the operator taps with his fingers on the opposite part of the hive, which will cause her majesty to run there, to ascertain the cause of the noise. If any bees are seen upon the combs removed, they may be brushed off with a feather, when they will generally return to the hive. The combs taken away are replaced either by empty ones, or by full combs taken from the lower part of the hive.

When hives are constructed on the principle of those shown in fig. 64, &c., consisting of several parts separable, laid one upon the other, the honey may be collected by causing the bees to desert the division intended to be removed by tapping on remote parts of the hive, and by projecting tobacco-smoke on them.

These operations may be performed in the day between ten and three o'clock. If the country be one rich in bee pasturage, a superior division of the hive may be taken away and replaced by an empty one, if the operation take place early in the season; and this latter may sometimes be again harvested before the close of the season, so as to obtain honey of the purest and finest quality.

But where the pasturage is not so rich, or where the operation is performed later in the season, it will be necessary either not to replace the division harvested, or to put the empty division at the bottom of the hive.

To collect the honey in the hives of the form represented in fig. 58, p. 49, called the vulgar hive, it is necessary either to expel the bees or to smother them.

To expel and transfer them to another hive, that which is to be harvested is inverted, as shown in fig. 58, p. 49, and over it is placed the hive to which the bees are to be transferred. The bees may be driven from one to the other, either by being smoked, as shown in fig. 76, p. 17, or by tapping upon the superior hive, fig. 58, p. 49.

If some bees remain in the hive to be harvested, they will voluntarily pass into the new hive by the arrangement represented in fig. 76, p. 17.

When the hive is harvested, either wholly or partially, by affecting the bees with temporary asphyxia, the process is as follows: after having beaten the black powder from a puff-ball of Lycoperdon, it is placed with some red charcoal in the fumigator, fig. 89, the nozzle of which is inserted at the door of the hive. The bellows being worked for five or six minutes, the bees will fall insensible from the hive, when the combs may be removed, wholly or partially, as the case may be. In twenty or thirty minutes the bees will revive, and re-enter the hive, or may be received in a new one if desired.

If it be not desired to preserve the bees, the hive may be placed over a pit into which they will fall, and where they may be buried.

To obtain honey of the first quality, the purest combs, containing neither bee-bread nor brood, being selected, are drained through a hair-sieve or osier-basket. Their product, called virgin honey, is limpid. It hardens and keeps if potted and put in a cool and dry place. Honey of inferior quality is obtained by pressing the residue of the combs, and exposing them to heat.

Whenever honey is collected, wax may also be obtained, but the latter substance may be separately collected at the close of the winter, by paring away the lower ranges of comb, taking away by the knife those which are old, black, and mouldy, and those which have been attacked by the moth. The wax is dissolved with boiling water, after which it is purified and collected in moulds of glazed pottery.

202. Honey and wax, the products of bee industry, form important articles of commerce in various parts of the world.

Although the production of wax is not confined to the bee, nearly all of that article employed in Europe is of bee manufacture.

Although honey has lost much of its importance as an article of food, since the discovery and improvement of the fabrication of sugar, it is still regarded as a luxury, and of considerable value in this country, as the material out of which a wholesome vinous beverage is produced. In many inland parts of the continent where sugar is costly, few articles of rural economy could be less spared. In the Ukraine some of the peasants possess from 400 to 500 hives, and are said to make more profit of their bees than even of their corn. In Spain the nurture of bees is carried to a still greater extent; according to Mills, a single parish priest was known to possess the almost incredible number of 5000 hives.

The common hive-bee is the same, according to Latreille, in every part of Europe, except in some districts of Italy, where a species called the Apis ligustica of Spinola is kept. This species is also said to be cultivated in the Morea and the Ionian Isles. Honey, however, is also obtained from many other species of bees, as well wild as domesticated.

203. The rock honey of some parts of America, which is very thin and as clear as water, is the produce of wild bees, which suspend their clusters of thirty or forty waxen cells, resembling a bunch of grapes, from a rock. In South America large quantities of honey are collected from nests built in trees by the Trigona Amalthea and other species of this genus, under which, according to Kirby, should be included the Bamburos, to gather the honey of which the whole population in Ceylon make excursions into the woods.

According to Agara, one of the chief articles of food of the Paraguay Indians is wild honey.

Captain Green observes, that in the Island of Bourbon, where he was stationed for some time, there is a bee which produces honey much esteemed there, of a green colour, having the consistency of oil, and which, besides the usual sweetness of honey, has a remarkable fragrance. This green honey is exported to India in considerable quantities, where it bears a high price.

A species of bee called the Apis fasciata was probably cultivated ages before the present hive-bee was attended to. This species is still so extensively cultivated in Egypt that Niebuhr met on the hill between Cairo and Damietta a convoy of 4000 hives, which the apiarists of that country were transporting from a region where the season had passed, to one where the spring was later.

204. This periodical migration of bees is by no means of modern date. According to Columella, the Greeks used to send their

bee-hives at certain seasons of the year from Achaia into Attica, and a similar custom still prevails in Italy, and even in this country in the neighbourhood of heaths.

Among the domesticated species of bees may be also mentioned the Apis unicolor in Madagascar, the Apis Indica at Pondicherry and in Bengal, and the Apis Adansonii at Senegal.

Fabricius affirmed that the Apis Acraensis laboriosa, and others in the East and West Indies, might be domesticated with greater advantage than even the common hive-bee of Europe, called the Apis mellifica.

205. Honey is one of the class of aliments which requires to be used with some precaution, since not only are certain constitutions of body affected injuriously by it, even in its most natural and wholesome state, but it happens occasionally that the insects which collect it resort to poisonous flowers, which impart their noxious properties to the honey extracted from them.

Kirby mentions the case of a lady of his acquaintance upon whom ordinary honey acted like poison, and says, that he heard of instances in which death ensued from eating it.

But where the bee unfortunately resorts to poisonous plants, the consequences are not thus limited to individuals of peculiar idiosyncrasies. Dr. Barton has given a remarkable example of this.*

In the autumn and winter of the year 1790, an extensive mortality was produced amongst those who had partaken of the honey, collected in the neighbourhood of Philadelphia. The attention of the American government was excited by the general distress; a minute enquiry into the cause of the mortality ensued, and it was satisfactorily ascertained that the honey had been chiefly extracted from the flowers of *Kalmia latifolia*. Though the honey mentioned in Xenophon's well-known account of the effect of a particular sort, eaten by the Grecian soldiers during the celebrated retreat, after the death of the younger Cyrus, did not operate fatally, it gave those of the soldiers who ate it in small quantities the appearance of being intoxicated, and such as partook of it freely, of being mad or about to die, numbers lying on the ground as if after a defeat. A specimen of this honey, which still retains its deleterious properties, was sent to the Zoological Society in 1834 from Trebizond, on the Black Sea, by Keith E. Abbott, Esq.

206. The maladies of the bee proceed from three causes,—hunger, damp, and infection; all of which admit of prevention when the insect is maintained artificially.

* American Philosophical Transactions, vol. v. of the year 1790.

Dysentery is the malady which is at once the most dreaded by bee-owner, and the most easy to be prevented. It is always due to damp or to bad diet, such as impure honey and indigestible syrups. The remedies are consequently to place the hives in a dry situation, and to supply the insects with wholesome food, such as good honey mixed with a little generous wine. The greatest care should also be taken to remove such combs as may be rendered foul by excrement, and to clean the shelves in the bee-houses.

Among other maladies may be mentioned, diseases of the antennæ, vertigo, and abortive broods of eggs. These are generally produced by bad food, damp, and drafts of cold air. On that account some bee-cultivators reject the forms of hive or bee-houses having two doors on opposite sides, thus placed for the purpose of ventilation. This arrangement is never seen in the natural habitations of the insect.

207. Dr. Bevan mentions a case of abortive brood which occurred in one of Mr. Dunbar's hives. The colony had been very strong in the previous autumn, and possessed a fertile queen, but in the spring it failed, and did not swarm. On examination, he found the four central leaves of the hive (which was one of Huber's, fig. 73), full of abortive brood, by the presence of which the queen seemed to be paralysed, though she still laid a few eggs at the edge of the combs. As the population seemed gradually diminishing, Mr. Dunbar cut out the whole of the abortive brood, removed the old queen, and added an after swarm to the family. The conjoined bees soon betook themselves to work, replaced the old combs by new ones, and laid in an ample store of honey. This is an operation called *castration* by French apiculturists; and in all such cases it is prudent, in order to prevent contagion, to have the infected combs burnt or buried.

208. Butler, in his "Female Monarchy," relates a story of a credulous lady who devoted herself to the cultivation of bees. This person having gone to receive the sacrament, retained the consecrated wafer; and at the suggestion of a friend, more simple than herself, placed it in one of her diseased hives. The bee plague, according to her report, immediately ceased; honey accumulated; and, on examining the inside of the hive, she found there, to her astonishment and admiration, a waxen chapel, of wondrous architecture, supplied with an altar, and even with a steeple, and a set of bells, all constructed of the same material.

209. The most dangerous enemies of the bees are the larvæ of certain moths, which when once they take possession of a hive cannot be extirpated, and no remedy remains but to transport the entire population of the insect colony to a new habitation.

The bee-louse, an insect about the size of a flea, often infests populous hives, so as greatly to annoy the bees by fixing itself upon them. Sometimes two or more attach themselves to a single bee, making it restless and indisposed for its usual industry.

A magnified view of one of these parasites is shown in fig. 92, as seen from above; and in fig. 93, as seen from below.

Fig. 92.—Bee Louse, seen from above.

Fig. 93.—Bee-Louse, seen from below.

That universal plunderer the wasp, and his formidable congener the hornet, often seize and devour them; sometimes ripping open their body to come at the honey, and at others carrying off that part in which it is situated. Wasps frequently take possession of a hive, having either destroyed or driven away its inhabitants, and consume all the honey it contains. Nay, there are certain idlers of their own species, called by apiarists, corsair bees, which plunder the hives of the industrious.

210. Examples have been already cited, in which bees have manifested peculiar personal antipathies, which have been ascribed, in the cases mentioned, to some odour, offensive to the insect, proceeding from the obnoxious individuals. Independently, however, of such general causes of hostility, the insects are sometimes provoked against even their best friends and most familiar acquaintances, by occasional circumstances. Kirby relates, that although he was generally exempt from their hostility, he could not venture with impunity to put them out of humour. Thus happening one day, during the season when asparagus was in blossom, to pass among the beds, which were crowded with bees, he discomposed them so much that he was obliged to make a hasty retreat, pursued by a swarm of his offended friends.

211. In Mungo Park's last mission to Africa, he was much annoyed by bees. His people, searching for honey, having disturbed a large colony of them, the insects sallied forth by myriads, and attacking men and beasts indiscriminately, put them all to the rout. One horse and six asses were killed or missing in consequence of their attack, and for half an hour the bees seem to have completely put an end to their journey. Isaacs, upon

another occasion, lost one of his asses, and one of his men was almost killed by them.*

212. Bees, however, as we have already observed, are not usually ill-tempered; and, if not molested, are generally inoffensive. Thorley relates,† that a maid servant, who assisted him in hiving a swarm, being rather afraid, put a linen cloth as a defence over her head and shoulders. When the bees were shaken from the tree on which they had alighted, the queen probably settled upon this cloth, for the whole swarm covered it, and then getting under it, spread themselves over her face, neck, and bosom, so that when the cloth was removed, she was quite a spectacle. She was with great difficulty kept from running off with all the bees upon her. But at length her master quieted her fears, and began to search for the queen. He succeeded, and expected that when he put her into the hive the bees would follow. He was, however, in the first instance disappointed, for they did not stir. Upon examining the cluster again, he found a second queen, or probably the former one, which had flown back to the swarm. Having seized her, he placed her in the hive, and kept her there. The bees soon missed her, and crowded into the hive after her, so that, in two or three minutes, not one remained on the poor frightened girl. After this escape she became quite a heroine, and would undertake the most hazardous employment about the hives.

213. The duels of rival queens have been already mentioned. Similar combats take place occasionally between the workers of one hive and those of another. Nor are such wars confined to single combats. General actions take place now and then between neighbouring colonies. This occurs when one takes a fancy to a hive which another has pre-occupied. Reaumur witnessed one of these battles, which lasted a whole afternoon, and in which great numbers fell on the one side and the other. In such cases, each combatant selects his opponent, and the victorious one flies away with the slain body of its enemy between its legs. After making a short flight thus, she deposits it on the ground, and rests near it, standing on her four anterior legs, and rubbing the two hinder legs against each other, as though she enjoyed the sight of her victim.

214. The following account of a bee battle was published in a Carlisle newspaper. A swarm of bees flying over a garden, where a newly tenanted hive was placed, suddenly stopped in their flight, and, descending, settled upon the hive, completely covering it. In a little time, they began to make their way to the door, and poured into it in such numbers, that it became completely

* Park's Last Mission, 153, 297. † Thorley, 150.

filled. A loud humming noise was heard, and the work of destruction immediately ensued. The winged combatants sallied forth from the hive until it became entirely emptied, and a ferocious battle commenced in the air between the besiegers and the besieged. These intrepid warriors were so numerous, that they literally darkened the sky overhead like a cloud. Meanwhile, the destructive battle raged with great fury on both sides, and the ground beneath was covered with the killed and wounded. Hundreds were seen dispersed on the ground, lying dead, or crawling about in a disabled state. To one party at length the palm of victory was awarded, and they settled upon a branch of an adjoining tree, from which they were removed to the deserted hive, of which they took quiet possession, and commenced and continued their usual industry.

STEAM NAVIGATION.

CHAPTER I.

1. Inventors of steam navigation uneducated.—2. First steamers on the Hudson and the Clyde.—3. Sea-going steamers due to British engineers.—4. Progress of steam navigation from 1812 to 1837.—5. Atlantic steamers projected.—6. Abstract possibility of the voyage could not be doubted.—7. The voyage had been already made by two steamers.—8. Projects advanced in 1836.—9. Discussion at Bristol in 1837.—10. Report of Dr. Lardner's speech in the *Times* of 27th August, showing the falsehood of the report that he pronounced the project impracticable.—11. Atlantic steam voyage advocated by Dr. Lardner in 1836-7.—12. The practical results of the various projects prove the truth of his predictions.—13. The Cunard steamers, established on the conditions suggested by him, were alone successful.—14. Voyages of these steamers.—15. Other lines established.—16. Probable extension of steam navigation to the general purposes of commerce.—17. Auxiliary steam-power the most probable means of accomplishing this.—18. Advantages of subaqueous propulsion.—19. Means of realising them.—20. Improved adaptation of steam-power to vessels of war required.—21. Mercantile steam-marine available for national defence.—22. Principle of marine-engine.—23. Propellers.—24. Paddle-wheels and screws.—25. Arrangement of paddle-wheels.—26. Paddle-shaft.—27. General arrangement of marine-engine.

1. If the spirits of Watt, Trevithick, and Fulton can look down on the things of this nether world, and behold the grand results their discoveries and inventions have produced, what triumph must be theirs! For half a century the steam-engine had remained a barren fact in the archives of science, when the self-taught genius of the Glasgow mechanic breathed into it the spirit of vitality, and conferred upon it energies by which it revived the drooping commerce of his country, and, when the auspicious epoch of general peace arrived, diffused its beneficial influence to the very skirts of civilisation. Scarcely had the fruit of the labour of Watt ripened, and this great mover been adopted as the principal power in the arts and manufactures, than its uses received that prodigious extension which resulted from its acquiring the LOCOMOTIVE character. As it had previously displaced animal power in the MILL, and usurped its nomenclature, so it now menaced its displacement on the ROAD. A few years more witnessed perhaps the greatest and most important of all the manifold agencies of steam—that by which it has given wings to the ship, and bade it laugh to scorn the opposing elements, transporting it in triumph over the expanse of the trackless ocean, regardless of wind or current, and conferring upon locomotion over the deep a regularity, certainty, and precision, surpassed by nothing save the movement of chronometers or the course of the heavenly bodies. Such are the vast results which have sprung from the intelligence of men, none of whom shared those privileges of mental culture enjoyed by the favoured sons of wealth; none of whom grew up within the walls of schools or colleges, drawing inspiration from the fountains of ancient learning; none of whom were spurred on by those irresistible incentives to genius arising from the competition of ardent and youthful minds, and from the prospect of scholastic honours and professional advancement. Sustained by that innate consciousness of power, stimulated by that irrepressible force of will, so eminently characteristic of, and inseparable from, minds of the first order, they, in their humble and obscure positions persevered against adverse and embarrassing circumstances, impelled by the faith that was in them, against the doubts, the opposition, and, not unfrequently, the ridicule of an incredulous world, until at length, by time and patience, truth was triumphant, and mankind now gathers the rich harvest sown by these illustrious labourers.

2. It was about the eighth year of the present century that Fulton launched the first steamboat on the Hudson. After the lapse of four years the first European steamboat was established on the Clyde. From that time the art of steam-navigation, in the two great maritime and commercial nations, advanced with a

steady and rapid progress. But it took different directions, governed by the peculiar geographical and commercial circumstances attending these countries. The genius and enterprise of the United States saw before and around it a vast territory, intersected by navigable rivers of unequalled length, forming lines of water communication on a colossal scale between its extensive interior and the sea-board. The Mississippi and its tributaries, with their sources, lost in distant tracts as yet untrodden by civilised man, and navigable by large vessels for many thousands of miles,—the Hudson, all but touching upon those magnificent inland seas that stretch along the northern boundary, and are almost connected with the Mississippi by the noble stream of the Illinois,—the Delaware, the vast Potomac, and, in fine, a coast thousands of miles in extent, fringed by innumerable bays and harbours, and land-locked basins having all the attributes of lakes,—these addressed themselves to the eye of the engineer and the capitalist, and determined the direction of enterprise. The application of steam power to inland navigation—the construction of vessels suited to traverse with speed, safety, and economy, rivers and lakes, harbours, bays, and extensive inlets—this was the task and the vocation of the American engineer, and this the interest of the capitalist and the merchant.*

3. The problem of steam-navigation, however, presented itself to the British engineer under other conditions. In a group of islands intersected by no considerable navigable rivers, and neither requiring nor admitting any inland navigation save that of artificial canals,—separated, however, from each other and from the adjacent continent of Europe by straits, channels, gulfs, and other arms of the sea,—it was apparent that if steam power should become available at all, it must be adapted to the navigation of these seas and channels—it must be adapted to accelerate and cheapen the intercourse between the British islands, between port and port upon their coasts, between them and the various ports on the adjacent coast of Europe, and finally to establish a communication with the Mediterranean and the coasts of Africa, Asia, and Europe, which are washed by it. While the American, therefore, was called on to contrive a steam-vessel adapted to inland and smooth-water navigation, the British engineer had the more difficult task, to construct one which should be capable of meeting and surmounting all the obstructions arising from the vicissitudes of the deep.

The result of the labour and enterprise of the English nation, directed to this inquiry, has been the present sea-going steam-ship.

* For a more developed notice of American Steam Navigation, see Railway Ec[illegible]omy, chap. xvi., and Museum, vol. ii. p. 17.

4. In the quarter of a century which elapsed between 1812 and 1837 steam-navigation made a steady and continuous, but not a sudden progress. The first lines of steamers were established naturally between the ports of England and the nearest sea-ports of Ireland on the one side, and France on the other. The length of each unbroken passage was then regarded as the great difficulty of the project. Thus steamers were established between Holyhead and Dublin, and between Dover and Calais, long before projectors ventured to try them between Dublin and Liverpool, or between London and the Low Countries.

After some years' experience, however, and the consequent improvement of the marine engine, passages of greater length were attempted with success. Lines of steamers were established first between more distant parts of the United Kingdom; as, for example, between London and Edinburgh, and between Dublin, Liverpool, and Glasgow. At a later period still longer trips became practicable, and lines of steamers were established between the United Kingdom and the Mediterranean; touching, however, for fuel at the peninsular ports, such as Corunna, Lisbon, and Gibraltar.

During this period, also, a fleet of steamers was constructed by government for post-office purposes, and a steam navy was gradually created, among which were found ships of large tonnage and considerable power.

5. At length, in the year 1836, a project, then considered as a startling one, was first announced, to supersede the far-famed New York and Liverpool packet-ships, by a magnificent establishment of STEAM-SHIPS.

These vessels were to sustain a constant, regular, and rapid communication between the New and Old World. They were to be the great channel for commerce, intelligence, and social intercourse, between the metropolis of the West and the vast marts of the United Kingdom; they were, in a word, to fulfil, not only all the functions which for half a century had been so admirably discharged by the packet-ships, but to do so with expedition increased in a threefold proportion at the least. Such an announcement could not fail to captivate the public. The results to be anticipated were so obvious, so grand, and must be attended with effects so widely spread, that all persons of every civilised nation at once felt and acknowledged their importance. The announcement of the project was accordingly hailed with one general shout of acclamation.

Some, who, being conversant with the actual condition of the art of steam-engineering as applied to navigation, and aware of various commercial conditions which must affect the problem, and were enabled to estimate calmly and dispassionately the difficulties and drawbacks, as well as the advantages, of the undertaking, entertained doubts which clouded the brightness of their hopes, and warned the commercial word against the indulgence of too sanguine anticipations, of the immediate and unqualified realisation of the project. They counselled caution and reserve against an improvident investment of extensive capital, in schemes which could still be only regarded as experimental, and which might prove its grave. But the voice of remonstrance was drowned amid the enthusiasm excited, by the promise of an immediate practical realisation of a scheme so grand. The keel of the Great Western was laid; an assurance was given that the seasons would not twice run through their changes, before she would be followed by a splendid line of vessels, which should consign the packet-ships to the care of the historian as "things that were."

6. It cannot be seriously imagined, that any one who had been conversant with the past history of steam-navigation, could entertain the least doubt of the abstract practicability of a steam-vessel making the voyage between Bristol and New York.

A vessel having as her cargo a couple of hundred tons of coals would, *cæteris paribus*, be as capable of crossing the Atlantic as a vessel transporting the same weight of any other cargo. A steam-vessel of the usual form and construction would, it is true, labour under comparative disadvantages, owing to obstructions presented by her paddle-wheels and paddle-boxes; but still it would have been preposterous to suppose that these impediments could have rendered her passage to New York impracticable.

7. But, independently of these considerations, it was a well-known fact, that, long antecedent to the epoch now adverted to, the Atlantic had actually been crossed by the steamers Savannah and Curaçoa. Nevertheless a statement was not only widely circulated, but generally credited, that I had publicly asserted that a steam voyage across the Atlantic was "*a physical impossibility!*"

Although this erroneous statement has been again and again publicly contradicted through various organs of the press, it continues nevertheless to be repeated. I shall therefore take this opportunity once more to put on record, what I really did state on the occasion, on which I am reported to have affirmed that the Atlantic steam voyage was a physical impossibility.

8. Projects had been started in the year 1836 by two different and opposing interests, one advocating the establishment of a line of steamers to ply between the west coast of Ireland and Boston, touching at Halifax; and the other a direct line, making an uninterrupted trip between Bristol and New York. In the year

1836, on the occasion of the meeting of the British Association in Dublin, I had advocated the former of these projects.

9. On the occasion of the next meeting in 1837 at Bristol, I again urged its advantages, and by comparison discouraged the project of a direct line between Bristol and New York. When I say that I advocated one of these projects, it is needless to add that the popular rumour, that I had pronounced the Atlantic voyage impracticable, is utterly destitute of foundation. But I am enabled to offer more conclusive proofs than this, that, so far from asserting that the Atlantic voyage by steam was impossible, *I distinctly affirmed the contrary.*

The *Times* newspaper sent a special reporter to attend the meeting at Bristol, and more particularly to transmit a report of the expected discussion on the Atlantic steam voyage, which at the moment excited much interest.

10. The meeting took place on the 25th, and the report appeared in the *Times* of the 27th of August. From that report I extract the following;—

"Dr. Lardner said he would beg of any one, and more especially of those who had a direct interest in the inquiry, to dismiss from their minds all previously-formed judgments about it, *and more especially upon this question, to be guarded against the conclusions of mere theory*, for if ever there was one point in practice of a commercial nature which, more than another, required to be founded on experience, it was this one of extending steam-navigation to voyages of extraordinary length. He was aware that since the question had arisen, it had been stated that his own opinion was averse to it. *This statement was totally wrong*, but he did feel that great caution should be used in the adoption of the means of carrying the project into effect. Almost all depended on the first attempt, for a failure would much retard the ultimate consummation of the project.

"Mr. Scott Russell said that he had listened with great delight to the lucid and logical observations they had just heard. He would add one word, Let them try this experiment, with a view only to the enterprise itself, but on no account try any new boiler or other experiment, but to have a combination of the most approved plans that had yet been adopted.

"After some observations from Messrs. Brunel and Field, Dr. Lardner, in reply, said, that *he considered the voyage practicable*, but he wished to point out that which would *remove the possibility of a doubt*, because if the first attempt failed it would cast a damp upon the enterprise, and prevent a repetition of the attempt."

Such was the report of the *Times* of the speech in which I was afterwards, and have ever since been, represented as having declared a steam voyage across the Atlantic a *mechanical impossibility!* *

11. What I did affirm and maintain in 1836-7 was, that the long sea voyages by steam which were contemplated, could not at that time be maintained with that regularity and certainty which are indispensable to commercial success, by any revenue which could be expected from traffic alone, and that, without a government subsidy of a considerable amount, such lines of steamers, although they might be started, could not be permanently maintained.

12. Now let us see what has been the practical result.

Eight steam-ships, including the Great Western, were, soon after the epoch of these debates, placed upon the projected line between England and New York; the Sirius, the Royal William, the Great Liverpool, the United States,† the British Queen, the President, the Great Western, and the Great Britain.

The Sirius was almost immediately withdrawn; the Royal William, after a couple of voyages, shared the same fate; the Great Liverpool, in a single season, involved her proprietors in a loss of 6000*l.*, and they were glad to remove her to the Mediterranean station. The proprietors of the British Queen, after sustaining a loss which is estimated at little less than 100000*l.*, sold that ship to the Belgian government. The United States was soon transferred, like the Great Liverpool, to the Mediterranean trade. The President was lost. The Great Western, as is well known, after continuing for some time to make the voyage in the summer months, being laid by during the winter, and after involving her proprietors in a loss of unknown and unacknowledged amount, was sold. Of the Great Britain, the fate is well known.

Thus, it appears, in fine, that after the lapse of nearly fourteen years, notwithstanding the great improvements which took place in steam navigation, the project advanced at Bristol, and there pronounced by me to be commercially impracticable, signally failed.

13. Meanwhile another project, based upon the conditions which I had indicated as essential to the permanence and success of the enterprise, was started.

Mr. Samuel Cunard, a Canadian, who had extensive experience

* Notices of this speech, substantially the same, appeared in the Edinburgh Review, the Monthly Chronicle, and other periodicals of that date.

† This vessel was not actually placed on the line, but was prepared for it. She was afterwards called the Oriental.

in maritime affairs, being associated with some large capitalists who had confidence in his sagacity and skill, laid before the British government a project for a line of Post-office steamers, to ply between Liverpool and Boston, touching at Halifax. But Mr. Cunard insisted strongly on the necessity of providing a considerable fleet of steamers, to ensure that permanence and regularity which were indispensable to the success of the project. He demonstrated that the magnitude of the capital it must involve, and the vast expenditure attending its maintenance, were such as could not be covered by any commercial returns to be expected from it, and that, consequently, it could only be sustained by a liberal subsidy to be furnished by the government. After much negotiation, it was agreed to grant him an annual subsidy of 60000*l*., upon which condition the enterprise was commenced. Mr. Cunard, however, had hardly embarked in it, before it became evident that this grant was insufficient, and it was soon increased to 100000*l*. per annum. Further experience proved that even this was insufficient to enable Cunard and his associates to maintain the communication in a satisfactory and efficient manner, and the annual subvention was in fine raised to its present amount, that is to say, 145000*l*. sterling per annum.

14. Thus supported, the communication was in 1851 maintained throughout the year. During the four winter months, December, January, February, and March, there were two departures per month from each side, and during the eight other months of the year there was a departure once a week, making a total of forty-four departures from each side, or forty-four voyages going and returning.

These voyages make a total distance sailed of 272800 geographical miles within the year. The subsidy, therefore, amounts to ten shillings and eightpence per mile sailed.

Since the epoch here referred to, steam-navigation has, as is well known, undergone great improvements, and its powers have been proportionally extended. The arrangements of this and other lines of ocean navigation have accordingly undergone, and continue to undergo, modifications having the effect of increasing the frequency and extending the lengths of the trips.

15. Soon after the Cunard line of steamers commenced operations, it was proposed to establish, with government support, a transatlantic line of steamers communicating between Great Britain and its West India colonies. Ultimately the present West India Steam-Packet Company was established, and obtained from the government a subvention greater still in amount than had been granted to the Cunard Company. The amount of this annual grant was 240000*l*.

16. Great as the progress of steam-navigation has been within the last quarter of a century, much still remains to be accomplished, before that vast agent of transport can be regarded as having been pushed to the limit of its powers. Its superior speed, regularity, and certainty, comparatively with sailing-vessels, have naturally first attracted to it passengers, despatches, and certain descriptions of merchandise to which expedition is important, and which can bear a high rate of freight. The mechanical conditions which ensure expedition in long voyages, exclude, to a great extent, the transport of general merchandise; for a large part of the tonnage of the vessel is occupied by the machinery and fuel. The heavy expenses, therefore, of the construction and maintenance of these vessels, must be defrayed by appropriating the profitable tonnage to those objects of transport alone which will bring the highest rate of freight. While the steamer, therefore, has allured from the sailing-vessel the chief part of the passenger traffic, the mails altogether, parcels, and some few objects of general traffic, the latter still continues in undisturbed possession of the transport business of general commerce.

The next step in the improvement of the art must therefore be directed to the construction of another class of steam-vessels, which shall bear to the present steam-ships the same relation which the goods-trains, on the railway, bear to the passenger-trains. As in the case of these goods-trains, expedition must be sacrificed to reduce the cost of transport to the limit which shall enable the merchandise to bear the freight. If the steamer for the general purposes of commerce can be made to exceed the sailing-vessel, in anything approaching to the ratio by which the goods-train on the railway exceeds the waggon or canal-boat, we shall soon see the ocean covered with such steamers, and the sailing-vessel will pass from the hands of the merchant to those of the historian.

17. To render steamers capable of attaining these ends, it will be evidently advisable to adopt measures, to combine the qualities of a sailing-vessel with those of a steamer. The ships must possess such steaming power as may give them that increased expedition, regularity, and punctuality, which, in the existing state of the arts, can only be obtained through that agency; but it is also important that they should accomplish this without robbing them, to any injurious extent, of their present capability of satisfying the wants of commerce.

18. In an early edition of my treatise on the Steam-Engine, published long before screw steam-vessels had attained the state of perfection to which they have now arrived, I stated that no expedient was more likely to accomplish this, than one which would

have for its object the removal of the paddle-wheels now generally used, and the substitution of some description of subaqueous propeller. A great reduction in the dimensions of the machinery, and the surrender to the uses of commerce of that invaluable space which it now occupies within the vessel, are also essential. It is incumbent on the engineer who assumes the high responsibility of the superintendence of such a project, to leave the ship in the full and unimpaired enjoyment of its functions as a sailing-vessel. Let him combine, in short, the agency of steam with the undiminished nautical power of the ship. Let him celebrate the marriage of the steam-engine with the sailing-vessel. If he accomplish this with the skill and success of which the project is susceptible, he may fairly hope that his name will go down to posterity as a benefactor of mankind, united with those of Fulton and Watt.

The actual progress of mechanical science encourages us to hope, that the day is fast approaching when such ideas will be realised —when we shall behold a great highway cut across the wide Atlantic, not as now, subserving to those limited ends, the attainment of which will bear a high expense, but answering all the vast and varied demands of general commerce. Ships which would serve the purposes we have here shadowed out, can never compete in mere speed with vessels in which cargo is nothing, expense disregarded, and expedition everything. Be it so. Leave to such vessels their proper functions; let them still enjoy to some extent the monopoly of the most costly branches of traffic, subsidised as they are by the British treasury. Let the commercial steam-ships, securing equal regularity and punctuality, and probably more frequent despatch, be content with somewhat less expedition. This is consistent with all the analogies of commerce.

There is another consideration which ought not to be omitted. In all great advances in the arts of life, extensive improvements are at first attended with individual loss of greater or less amount. The displacement of capital is almost inevitably attended with this disadvantage. It is the duty, therefore, of the scientific engineer, in the arrangement and adoption of his measures, to consider how these objects may be best attained with the least possible injury to existing interests. To accomplish this will not only be a benefit to the public, but will materially facilitate the realisation of his own objects, by conciliating in their favour those large and powerful interests, whose destruction would be otherwise menaced by them. If, then, in the present case, it is found practicable with advantage to introduce into the present sailing-ships, more especially into those most recently constructed, the agency of steam, a very important advantage will be gained for the public, and the almost unanimous support and countenance of the commercial community will be secured.

19. To attain the objects here developed, it will be evidently indispensable to remove those impediments, which at once disfigure the appearance and destroy the efficiency of the sailing qualities of the ship, by the enormous and unsightly excrescences projecting from the sides in the shape of paddle-wheels, and the wheel-houses or paddle-boxes, as they are called. These appendages are attended with many evils, the least of which is perhaps the impediment which they present to the progress of the ship.

But the form, magnitude, and position of the propelling machinery, is far from being the only obstacle to the full success of the present steam-vessels, when directed to the general purposes of commerce. The engines themselves, and the boilers, from which the moving power proceeds, and the fuel by which they are worked, occupy the very centre of the vessel, and engross the most valuable part of the tonnage. The chimney, which gives efficacy to the furnaces, is also an unsightly excrescence, and no inconsiderable obstruction.

When long ocean-voyages are contemplated, such as those between New York and the ports of England, there is another serious obstacle, which is especially felt in the westward trip, because of the prevalence of adverse winds. When the vessel starts on its long voyage, it is necessarily laden with a large stock of fuel, which is calculated to meet, not merely the average exigencies of the voyage, but the utmost extremity of adverse circumstances of wind and weather to which it can by possibility be exposed. This fuel is gradually consumed upon the voyage; the vessel is proportionally lightened, and its immersion diminished. If its trim be so regulated that the immersion of its wheels at starting be such as to give them complete efficiency, they may, before the end of the voyage, be almost if not altogether raised out of the water. If, on the other hand, the efficiency of propulsion in the latter part of the voyage be aimed at, they must have such a depth at its commencement as to impair in a serious degree their propelling effect, and to rob the vessel of its proper speed. Under such circumstances, there is no expedient left but compromise. The vessel must start with too great and arrive with too little immersion. There is no alternative, save to abandon altogether the form and structure of the present machinery, and to awaken the inventive genius of the age to supply other mechanical expedients, which shall not be obnoxious to these objections.

In fine, then, we look to the improvement of auxiliary steam power, and the extended use of submerged propellers, as the means which, in the existing state of the art of steam-navigation, are most likely to extend the benefits of that agent of transport to general commerce.

20. If the form and structure of paddle-wheel steam-vessels be obnoxious to these many serious objections, when considered with reference to the purposes of general commerce, they are still more objectionable when considered with reference to the purposes of national defence. It is undoubtedly a great power with which to invest a vessel of war, to be able to proceed at will, in spite of the opposition of wind or tide, in any direction which may seem most fit to its commander. Such a power would have surpassed the wildest dreams of the most romantic and imaginative naval commander of the last century. To confer upon the vessels of a fleet the power immediately, at the bidding of the commander, to take any position that may be assigned to them relatively to the enemy, or to run in and out of a hostile port at pleasure, or fly with the rapidity of the wind past the guns of formidable forts, before giving them time to take effect upon them—are capabilities which must totally revolutionise all the established principles of naval tactics. But these powers at present are not conferred upon steam-ships, without important qualifications and serious drawbacks. The instruments and machinery from which they are immediately derived are, unfortunately, exposed in such a manner as to render the exercise of the powers themselves hazardous in the extreme. It needs no profound engineering knowledge to perceive that the paddle-wheels are eminently exposed to shot, which, taking effect, would altogether disable the vessel, and leave her at the mercy of the enemy; and the chimney is even more exposed, the destruction of which would render the vessel a prey to the enemy within itself in the shape of fire. But besides these most obvious sources of exposure in vessels of the present form intended as a national defence, the engines and boilers themselves, being more or less above the water line, are exposed so as to be liable to be disabled by shot.

A war steamer, to be free from these objections, should be propelled by subaqueous apparatus. Her engines, boilers, and all other parts of her machinery should be below the water-line. Her fuel should be hard coal, burning without visible smoke, so that her approach may not be discoverable from a distance. Her furnaces might be worked by blowers, so that the chimney might be dispensed with, and thus its liability to be carried away by shot removed.

21. The policy of the British government has been to rely on the commercial steam navy as a means of national defence, in the event of the sudden outbreak of war. By the evidence given

before a committee of the House of Commons in 1850, and the report founded thereupon, it appeared that commercial steamers in general are capable of war service, with no other previous alteration or preparation than such as are easily practicable and expeditiously executed. It was shown that all steamers of 400 tons and upwards would be capable, with some additional strengthening, to carry such pivot guns as are used in war-steamers, and that there are few mercantile steamers of any size, which might not carry an armament such as would render them useful in case of an emergency.

22. The principle on which the steam-engine is applied to the propulsion of ships is the same as that by which oars act in propelling boats. In both cases the propelling instruments having a point or points of reaction on the vessel, are made to drive a mass of water backwards, and the moving force, or momentum, thus imparted to the water from stem to stern, is necessarily attended with a reaction from stern to stem, which, taking effect on the vessel, gives it a corresponding progressive motion.

By the well-known mechanical principle of the composition and resolution of force, it can be demonstrated that whatever force may be imparted to the water by the propeller, such force can be resolved into two elements, one of which is parallel, and the other in a plane at right angles to the keel. The former alone can have a propelling effect, and since the latter is wholly ineffective, the propeller should always be so constructed that its whole force, or at least the chief part of it, shall be employed in driving the water in a direction parallel to the keel from stem to stern.

23. The mechanical expedients by which the power of steam is rendered available for the propulsion of vessels are very various, both as regards the form of the engine which acts upon the propeller, and the form of the propeller itself.

In all cases hitherto reduced to practice, the propeller is a wheel fixed upon a horizontal shaft, to which the engine imparts a motion of continued rotation. The wheel is so constructed that when it revolves it imparts to a volume of water, more or less considerable, a motion either directly backwards, or one whose principal component has that direction. The greater the proportion which this principal component has to the entire force exercised by the propeller, the more effective it will be.

24. The propellers hitherto practically applied in steam-navigation are of two kinds, called *paddle-wheels* and *screws*.

The shaft of the paddle-wheels is fixed horizontally across the vessel, and consequently at right angles to the direction of the keel.

The shaft of the screws is placed horizontally in the vessel parallel to the keel, and directly above it.

The faces of the paddle-wheels look sideways and are consequently parallel to the keel.

The faces of the screws look sternwards, and are consequently at right angles to the keel.

25. The paddle-wheels are in pairs one at each side of the vessel and outside the hull, being supported on the projecting ends of the paddle-shaft, and covered by large semi-cylindrical drums called *paddle-boxes.*

The screws are generally single wheels, within the vessel under its hull, and placed near the stern.

Only the lower parts of the paddle-wheels are immersed. The screws are altogether submerged.

26. The paddle-shaft being carried on each side beyond the timbers of the vessel, the wheels supported by it and revolving with it, are usually constructed like undershot water-wheels, having attached to their rims a number of flat boards called *paddle-boards.* As the wheels revolve, these paddle-boards strike the water, driving it in a direction contrary to that in which it is intended the vessel should be propelled. On the paddle-shaft two cranks are constructed, similar to the crank on the axle of the fly-wheel of a stationary engine. These cranks are generally placed at right angles to each other, so that when either is in its highest or lowest position the other shall be horizontal. They are driven by two steam-engines, which are usually placed in the hull of the vessel below the paddle-shaft. In the earlier steam-boats a single steam-engine was used, and in that case the unequal action of the engine on the crank was equalised by a fly-wheel. This, however, has been long since abandoned in European vessels, and the use of two engines is now almost universal. By the relative position of the cranks it will be seen, that when either crank is at its dead point the other will be in one of the positions most favourable to its action, and in all intermediate positions, the relative efficiency of the cranks will be such as to render their combined action very nearly uniform.

The steam-engines used to impel vessels may be either condensing engines, similar to those of Watt, and such as are used in manufactures generally, or they may be non-condensing and high-pressure engines, similar in principle to those used on railways. Low-pressure condensing engines are, however, universally used for marine purposes in Europe, and to a great extent in the United States. In the latter country, however, high-pressure engines are also used in some of the river steamers.

27. The arrangement of the parts of a marine engine differs in

some respects from that of a land engine. The limitation of space, which is unavoidable in a vessel, renders greater compactness necessary. The paddle-shaft on which the cranks to be driven by the engine are constructed being very little below the deck of the vessel, the beam, if there be one, and connecting rod could not be placed in the position in which they usually are in land engines, without carrying the machinery to a considerable elevation above the deck. This is done in the steam-boat engines used on the American rivers; but it would be inadmissible in steam-boats in general, and more especially in sea-going steamers. The connecting rods, therefore, instead of being presented downwards towards the cranks which they drive, must, in steam-vessels, be presented upwards, and the impelling force be received from below. If, under these circumstances, the beam were in the usual position above the cylinder and piston-rod, it must necessarily be placed between the engine and the paddle-shaft. This would require a depth for the machinery which would be incompatible with the magnitude of the vessel. The beam, therefore, of marine engines, instead of being above the cylinder and piston, is placed below them. To the top of the piston rods, cross-pieces are attached, of greater length than the diameter of the cylinders, so that their extremities shall project beyond the cylinders. To the ends of these cross-pieces are attached by joints the rods of a parallel motion: these rods are carried downwards, and are connected with the ends of two beams below the cylinder, and placed on either side of it. The opposite ends of these beams are connected by another cross-piece, to which is attached a connecting rod, which is continued upwards to the crank-pin, to which it is attached, and which it drives. Thus the beam, parallel motion, and connecting rod of a marine engine, are similar to those of a land engine, only that they are turned upside down; and in consequence of the impossibility of placing the beam directly over the piston rod, two beams and two systems of parallel motion are provided, one on each side of the engine, acted upon by, and acting on the piston rod and crank by cross-pieces.*

The proportion of the cylinders differs from that usually observed in land engines for like reasons. The length of the cylinder of land engines is generally greater than its diameter, in the proportion of about two to one. The cylinders of marine engines are, however, commonly constructed with a diameter greater than their length. In proportion, therefore, to their power their stroke is shorter, which infers a corresponding short-

* We must assume that the reader of the present Tract has already rendered himself familiar with the several Tracts on Steam and the Steam Engine, already published in the Museum.

ness of crank and a greater limitation of play of all the moving parts in the vertical direction. The valves and the gearing by which they are worked, the air-pump, the condenser and other parts of the marine engines, do not differ in principle from those already described in land engines.

These arrangements will be more clearly understood by reference to fig. 1, in which is represented a longitudinal section of one of the many varieties of beam engine, with its boiler as placed in a steam-vessel. The sleepers of oak, supporting the engine, are represented at X, the base of the engine being secured to these by bolts passing through them and the bottom timbers of the vessel; S is the steam-pipe leading from the steam-chest in the boiler to the slides *c*, by which it is admitted to the top and bottom of the cylinder. The condenser is represented at B, and the air-pump at E. The hot well is seen at F, from which the feed is taken for the boiler; L is the piston-rod connected by the parallel motion *a*, with the beam H, working on a centre K, near the base of the engine. The other end of the beam I drives the connecting rod M, which extends upwards to the crank, which it works upon the paddle-shaft O. Q R is the framing by which the engine is supported. The beam here exhibited is shown on dotted lines as being on the further side of the engine. A similar beam similarly placed, and moving on the same axis, must be understood to be at this side connected with the cross-head of the piston in like manner by a parallel motion, and with a cross-piece attached to the lower end of the connecting rod and to the opposite beam. The eccentric which works the slides is placed upon the paddle-shaft O, and the connecting arm which drives the slides may be easily detached when the engine requires to be stopped. The section of the boiler, grate, and flues is represented at W U. The safety-valve *y* is enclosed beneath a pipe carried up beside the chimney, and is inaccessible to the engine man; *h* are the cocks for blowing the salted water from the boiler, and I I the feed-pipe.

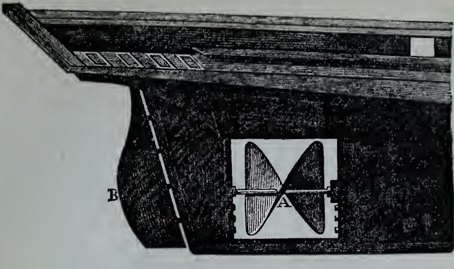


Fig. 2.—FORM AND POSITION OF THE SCREW.

STEAM NAVIGATION.

CHAPTER II.

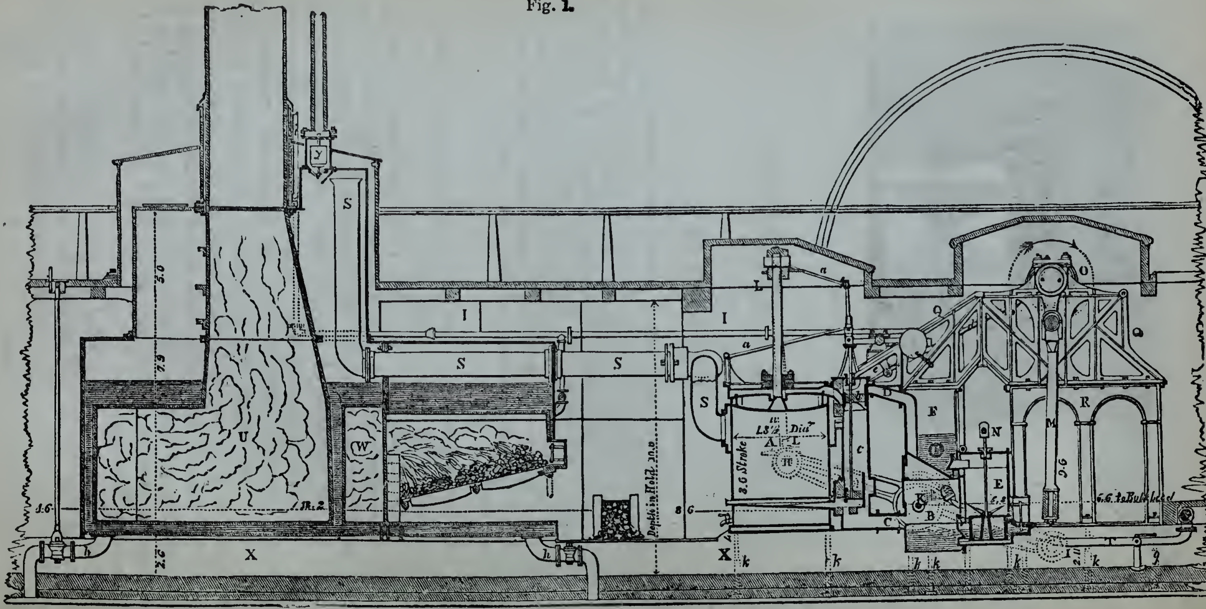
28. Arrangement of the engine-room ; governor and other regulating parts omitted.—29. Flue boilers and tubular boilers.—30. Construction of flue boilers.—31. Tubular boilers.—32. Indications of engineering ignorance.—33. Number and dimensions of tubes.—34. Incrustation produced by sea water.—35. Hydrometric indicators.—37. Thermometric indicators.—38. Seaward's contrivance.—39. Brine-pumps.—40. Blowing out.—41. To detach the scale.—42. Effect of corrosion.—43. Efficiency and economy of fuel.—44. Coating the boiler and pipes with felt.

28. The general arrangement of the engine-room of a steam-vessel is represented in fig. 3, page 131.

The nature of the effect required to be produced by marine engines, does not render either necessary or possible that great regularity of action, which is indispensable in a steam-engine applied to the purposes of manufacture. The agitation of the surface of the sea will cause the immersion of the paddle-wheels to be subject to great variation, and the resistance produced by the water to the engine will undergo a corresponding change. The governor, therefore, and other parts of the apparatus, contrived for giving to the engine that great regularity required in manufactures, are omitted in nautical engines, and nothing is introduced save what is necessary to maintain the machine in its full working efficiency.

Marine boilers are constructed in forms so infinitely various, that, in a notice so brief and popular as the present, we can only indicate some of their more general arrangements, and aid the

Fig. 1.


S
I
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k
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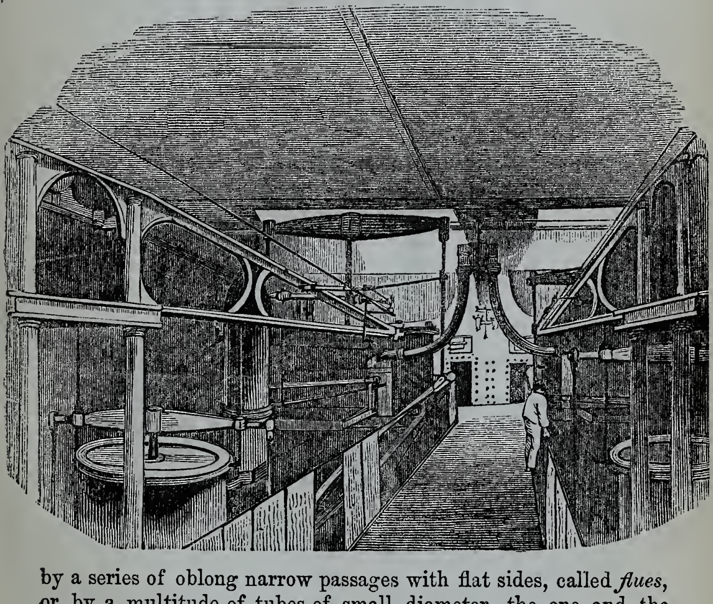
explanation by figures representing examples of particular classes of them.

29. To save space, they are constructed so as to produce the necessary quantity of steam, within the smallest possible dimensions. With this view a more extensive surface in proportion to the capacity of the boiler is exposed to the action of the fire. The flues, by which the flame and heated air are conducted to the chimney, are generally so constructed that the heated air issuing from the furnaces may be made to pass through the boiler, either

Fig. 3.



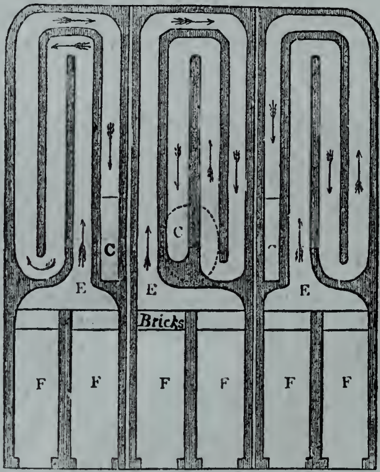
by a series of oblong narrow passages with flat sides, called *flues*, or by a multitude of tubes of small diameter, the one and the other leading from the furnaces to the base of the chimney, and being everywhere below the level of the water in the boiler. The former are called *flue boilers*, and the latter *tubular boilers*.

30. In the former class of boilers the flues are so formed as to traverse the boiler backwards and forwards several times before they terminate in the chimney. Such an arrangement renders the expense of the boilers greater than that of common land boilers, but their steam-producing power is greatly augmented. Experiments made by Mr. Watt, at Birmingham, proved that such boilers with the same consumption of fuel will produce, as compared with

common land boilers, an increased evaporation in the proportion of about three to two.

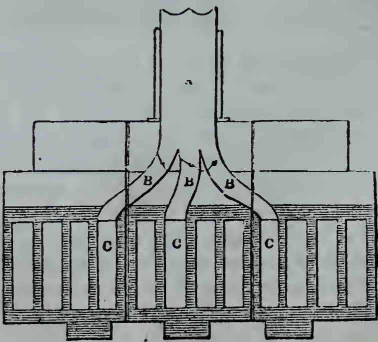
The form and arrangement of the water-spaces and flues in flue boilers are infinitely various. The sections of such boilers are exhibited in figs. 4, 5, 6. A section made by a horizontal

Fig. 4.



plane passing through the flues is exhibited in fig. 4. The furnaces F communicate in pairs with the flues E, the air following the course through the flues represented by the arrows. The flue E passes to the back of the boiler, then returns to the front, then

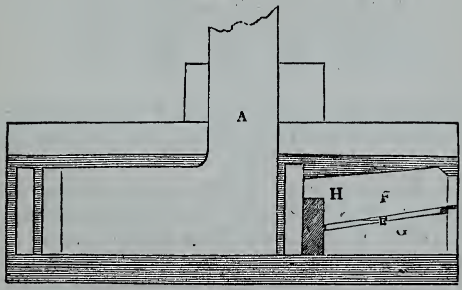
Fig. 5.



to the back again, and is finally carried back to the front, where it communicates at C with the curved flue B, represented in the transverse vertical section, fig. 5. This curved flue B finally terminates in the chimney A. There are, in this case, three independent boilers, each worked by two furnaces communicating with the same system of flues; and in the curved flues B, fig. 5, by which the air is finally conducted through the chimney, are placed three independent dampers, by means of which the furnace of each boiler can be regulated independently of the other, and by which each boiler may be separately detached from communication with the chimney.

A longitudinal section of the boiler, made by a vertical plane extending from the front to the back, is given in fig. 6, where F, as before, is the furnace, G the grate-bars sloping downwards from the front to the back, H the fire-bridge, C the commencement of the flues, and A the chimney. An elevation of the front of the

Fig. 6.



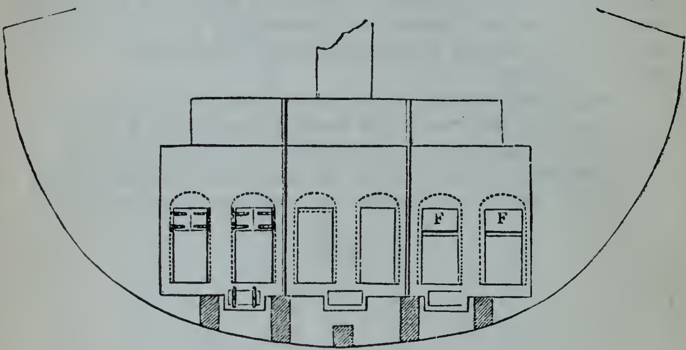
boiler is represented in fig. 7, showing two of the fire-doors closed and the other two removed, displaying the position of the grate-bars in front. Small openings are also provided, closed by proper doors, by which access can be had to the under-side of the flues, between the foundation timbers of the engine, for the purpose of cleaning them.

Each of these boilers can be worked independently of the others. By this means, when at sea, the engine may be worked by any two of the three boilers, while the third is being cleaned and put in order.

In the boilers here represented the flues are all upon the same level, winding backwards and forwards without passing one above the other. In other boilers, however, the flues, after passing backwards and forwards near the bottom of the boiler, turn upwards and pass backwards and forwards through a level of the water nearer its surface, finally terminating in the chimney. More heating surface is thus obtained with the same capacity of boiler.

It is found in practice, that the most efficient parts of the flue-surface for the generation of steam, are those which are horizontal

Fig. 7.



and at the upper parts of the flue, and the least efficient those which are horizontal and at the lowest part, the efficiency of the vertical sides being intermediate.

Since the flues are liable occasionally to become choked with soot and ashes, it is necessary that their magnitude shall be sufficient to allow a boy to enter them for the purpose of cleaning them.

31. Tubular marine boilers are constructed on a principle precisely similar to that of locomotive boilers, described in a former Tract. The flame and gaseous products of combustion, issuing from the furnace at a very elevated temperature, pass through a great number, sometimes several hundred, tubes of iron or brass, of about three inches diameter, which traverse the boiler below the level of the water in it, so that before they enter the chimney their temperature is reduced to a comparatively low point, the heat they thus lose being taken up by the water surrounding the tubes.

Flue boilers have the advantage over tubular boilers in being cheaper and more durable. With the same evaporating power they are however one-third larger and heavier, and consequently occupy a greater portion of the tonnage, and produce, other things being the same, a proportionally greater displacement, the latter condition augmenting the resistance, and therefore either diminishing the speed, or increasing the consumption of fuel.

32. There cannot be a more striking proof of the ignorance of general principles which prevails, respecting this branch of steam engineering, than the endless variety of forms and proportions which are adopted in the boilers and furnaces which are constructed, not only by different engineers but by the same engineer, for steamers of like power and capacity, and even for the same steamer at different times. Thus the original boilers of the *Great Western*, built for the New York and Bristol or Liverpool voyage, were of the common flue sort. They were subsequently taken out and replaced by tubular boilers. The dimensions and relative proportions of these two sets of boilers, thus supplied to the same vessel for the same voyage, differing as completely one from the other as if they had been designed for different vessels and different voyages.

On contemplating engineering proceedings, such as are exhibited in the preceding table, it is impossible to deny that practical men in such cases are groping in the dark, without the slightest benefit from the light which they ought to derive, from the present advanced state of physical science.

33. Tubular flues have been in many steamers adopted in preference to the flat and longer flues already described. In the second set of boilers of the *Great Western* above mentioned, the tubes were eight feet in length and three inches in diameter. In the boilers of the steamer *Ocean*, which are also tubular, the following are the principal dimensions:—

Boilers:	
Number	3
Length	14 feet.
Breadth	$19\frac{1}{2}$ feet.
Furnaces:	
Number	7
Length	7 feet.
Breadth	$2\frac{11}{12}$ feet.
Tubes:	
Material	Iron.
Number	378
Length	9 feet
Diameter	$3\frac{1}{4}$ inches.
Cylinders:	
Number	2
Diameter	56 inches.
Stroke	$5\frac{1}{2}$ feet.
Pressure of steam above atmosphere	$4\frac{1}{2}$ lbs. per in.
Consumption of coal per hour	18 cwt.

Among the more recent specifications of the machinery of marine engines submitted to the Admiralty, are some in which the boilers are traversed by nearly 2000 tubes of $3\frac{1}{2}$ inches external diameter, and five feet in length, giving a total heating surface of about 9000 square feet.

34. A formidable difficulty in the application of the steam-engine to sea voyages has arisen from the necessity of supplying the boiler with sea water instead of fresh water. The sea water is injected into the condenser for the purpose of condensing the

steam, and, mixed with the condensed steam, it is thence conducted as feeding water into the boiler.

Sea water holds, as is well known, certain saline and alkaline substances in solution, the principal of which is muriate of soda, or common salt. Ten thousand grains of pure sea water contain two hundred and twenty grains of common salt, the remaining ingredients being thirty-three grains of sulphate of soda, forty-two grains of muriate of magnesia, and eight grains of muriate of lime. The heat which converts pure water into steam does not at the same time evaporate those salts which the water holds in solution. As a consequence it follows, that, as the evaporation in the boiler is continued, the salt, which was held in solution by the water which has been evaporated, remains in the boiler, and enters into solution with the water remaining in it. The quantity of salt contained in sea water being considerably less than that which water is capable of holding in solution, the process of evaporation for some time is attended with no other effect, than to render the water in the boiler a stronger solution of salt. If, however, this process be continued, the quantity of salt retained in the boiler having constantly an increasing proportion to the quantity of water, it must at length render the water in the boiler a saturated solution; that is, a solution containing as much salt as, at the actual temperature, it is capable of holding in solution. If, therefore, the evaporation be continued beyond this point, the salt disengaged from the water evaporated, instead of entering into solution with the water remaining in the boiler, will be precipitated in the form of sediment; and if the process be continued in the same manner, the boiler would at length become a mere salt-pan.

But besides the deposition of salt sediment in a loose form, some of the constituents of sea water having an attraction for the iron of the boiler, collect upon it in a scale or crust, in the same manner as earthy matters, held in solution by spring water, are observed to form and become incrusted on the inner surface of land-boilers and of common culinary vessels.

The coating of the inner surface of a boiler by incrustation, and the collection of salt sediment in its lower parts, are attended with effects highly injurious to the materials of the boiler. The crust and sediment thus formed within the boiler are almost non-conductors of heat, and placed, as they are, between the water contained in the boiler and the metallic plates which form it, they obstruct the passage of heat from the outer surface of the plates in contact with the fire, to the water. The heat, therefore, accumulating in the boiler-plates so as to give them a much higher temperature than the water within the boiler, has the effect of softening them, and by the unequal temperature which will thus be imparted to the lower plates which are incrusted, compared with the higher parts which may not be so, an unequal expansion is produced, by which the joints and seams of the boiler, are loosened and opened, and leaks produced.

These injurious effects can only be prevented by either of two methods; first, by so regulating the feed of the boiler that the water it contains shall not be suffered to reach the point of saturation, but shall be so limited in its degree of saltness that no injurious incrustation or deposit shall be formed; secondly, by the adoption of some method by which the boiler may be worked with fresh water. This end can only be attained by condensing the steam by a jet of fresh water, and working the boiler continually by the same water, since the supply of fresh water sufficient for a boiler worked in the ordinary way, could never be commanded at sea.

The method by which the saltness of the water in the boiler is most commonly prevented from exceeding a certain limit, has been to discharge from the boiler into the sea a certain quantity of over-salted water, and to supply its place by sea water introduced into the condenser through the injection-cock, for the purpose of condensing the steam, this water being mixed with the steam so condensed, and being, therefore, a weaker solution of salt than common sea water. To effect this, cocks called *blow-off cocks* are usually placed in the lower parts of the boiler, where the over-salted, and therefore heavier, parts of the water collect. The pressure of the steam and incumbent weight of the water in the boiler force the lower strata of water out through these cocks; and this process, called *blowing out*, is, or ought to be practised at such intervals as will prevent the water from becoming over-salted. When the salted water has been blown out in this manner, the level of the water in the boiler is restored by a feed of corresponding quantity.

This process of blowing out, on the due and regular observance of which the preservation and efficiency of the boiler mainly depend, is too often left at the discretion of the engineer, who is, in most cases, not even supplied with the proper means of ascertaining the extent to which the process should be carried. It is commonly required that the engineer should blow out a certain portion of the water in the boiler every two hours, restoring the level by a feed of equivalent amount; but it is evident that the sufficiency of the process, founded on such a rule, must mainly depend on the supposition, that the evaporation proceeds always at the same rate, which is far from being the case with marine boilers.

35. An indicator, by which the saltness of the water in the boiler would always be exhibited, ought to be provided, and the

process of blowing out should be regulated by the indications of that instrument. To blow out more frequently than is necessary is attended with a waste of fuel; for hot water is thus discharged into the sea while cold water is introduced in its place, and consequently all the heat necessary to produce the difference of the temperatures of the water blown out, and the feed introduced, is lost. If, on the other hand, the process of blowing out be observed less frequently than is necessary, then more or less incrustation and deposit may be produced, and the injurious effects already described ensue.

36. As the specific gravity of water holding salt in solution is increased with every increase of the strength of the solution, any form of hydrometer capable of exhibiting a visible indication of the specific gravity of the water contained in the boiler, would serve the purpose of an indicator, to show when the process of blowing out is necessary, and when it has been carried to a sufficient extent. The application of such instruments, however, would be attended with some practical difficulties in the case of sea boilers.

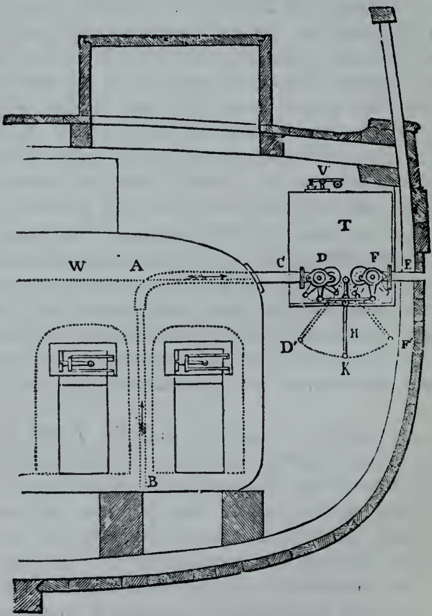
37. The temperature at which a solution of salt boils under a given pressure varies considerably with the strength of the solution; the more concentrated the solution is, the higher will be its boiling temperature under the same pressure. A comparison, therefore, of a steam-gauge attached to the boiler, and a thermometer immersed in it, showing the pressure and the temperature, would always indicate the saltness of the water; and it would not be difficult so to graduate these instruments as to make them at once show the degree of saltness.

If the application of the thermometer be considered to be attended with practical difficulty, the difference of pressures under which the salt water of the boiler and fresh water of the same temperature boil, might be taken as an indication of the saltness of the water in the boiler, and it would not be difficult to construct upon this principle a self-registering instrument, which would not only indicate but record from hour to hour the degree of saltness of the water. A small vessel of distilled water being immersed in the water of the boiler would always have the temperature of that water, and the steam produced from it communicating with a steam-gauge, the pressure of such steam would be indicated by that gauge, while the pressure of the steam in the boiler under which pressure the salted water boils might be indicated by another gauge. The difference of the pressures indicated by the two gauges would thus become a test, by which the saltness of the water in the boiler would be measured. The two pressures might be made to act on opposite ends of the same column of mercury contained in a siphon tube, and the difference of the levels of the two surfaces of the mercury, would thus become a measure of the saltness of the water in the boiler. A self-registering instrument, founded on this principle, formed part of the self-registering steam-log which I proposed to introduce into steam-vessels some time since.

38. The Messrs. Seaward of Limehouse adopted, in some of their engines, a method of indicating the saltness of the water, and of measuring the quantity of salted water or brine discharged by blowing out. A glass-gauge, similar in form to that already described in land engines, is provided, to indicate the position of the surface of the water in the boiler. In this gauge two hydrometer balls are provided, the weight of which in proportion to their magnitude is such, that they would both sink to the bottom in a solution of salt of the same strength as common sea water. When the quantity of salt exceeds $\frac{5}{32}$ parts of the whole weight of the water, the lighter of the two balls will float to the top; and when the strength is further increased until the proportion of salt exceeds $\frac{6}{32}$ parts of the whole, then the heavier ball will float to the top. The actual quantity of salt held in solution by sea water in its ordinary state is $\frac{1}{32}$ part of its whole weight; and when by evaporation the proportion of salt in solution has become $\frac{9}{32}$ parts of the whole, then a deposition of salt commences. With an indicator such as that above described, the ascent of the lighter hydrometer ball gives notice of the necessity for blowing out, and the ascent of the heavier may be considered as indicating the approach of an injurious state of saltness in the boiler.

The ordinary method of blowing out the salted water from a boiler is by a pipe, having a cock in it leading from the boiler through the bottom of the ship, or at a point low down at its side. Whenever the engineer considers that the water in the boiler has become so salted, that the process of blowing out should commence, he opens the cock communicating by this pipe with the sea, and suffers an indefinite and uncertain quantity of water to escape. In this way he discharges, according to the magnitude of the boiler, from two to six tons of water, and repeats this at intervals of from two to four hours, as he may consider to be sufficient. If, by observing this process, he prevents the boiler from getting incrusted during the voyage, he considers his duty to be effectually discharged, forgetting that he may have blown out many times more water than is necessary for the preservation of the boiler, and thereby produced a corresponding and unnecessary waste of fuel. In order to limit the quantity of water discharged, Messrs. Seaward adopted the following method. In fig. 8 is represented a transverse section of a part of a steam-vessel; W is the water-line of the boiler, B is the mouth of a blow-off pipe, placed near the bottom of the boiler. This pipe rises to A, and turning in the horizontal direction, A C, is conducted to a tank T, which contains exactly a ton of water. This pipe communicates with the tank by a cock D, governed by a lever H. When this lever is moved to D′, the cock D is open, and when it is moved to K, the cock D is closed. From the same tank there proceeds another pipe E, which issues from the side of the vessel into the sea, governed by a cock F, which is likewise put in

Fig. 8.



connection with the lever H, so that it shall be opened when the lever H is drawn to the position F′, the cock D′ being closed in all positions of the lever between K and F′. Thus, whenever the cock F communicating with the sea is open, the cock D communicating with the boiler is closed, and *vice versâ*, both cocks being closed when the lever is in the intermediate position K. By this arrangement the boiler cannot, by any neglect in blowing off, be left in communication with the sea, nor can more than a ton of water be discharged except by the immediate act of the engineer. The injurious consequences are thus prevented which sometimes ensue, when the blow-off cocks are left open by any neglect on the part of the engineer. When it is necessary to blow off, the engineer moves the lever H to the position D′. The pressure of the steam in the boiler on the surface of the water forces the salted water or brine up the pipe B A, and through the open cock C into the tank, and this continues until the tank is filled: when that takes place, the lever is moved from the position D′ to the position F′, by which the cock D is closed, and the cock F opened. The water in the tank flows through the pipe E into the sea, air being admitted through the valve V, placed at the top of the tank, opening inwards. A second ton of brine is discharged by moving the lever back to the position D′, and subsequently returning it to the position F′; and in this way the brine is discharged ton by ton, until the supply of water from the feed which replaces it has caused both the balls in the indicator to sink to the bottom.

39. A different method of preserving the requisite freshness of the water in the boiler was adopted by Messrs. Maudslay and Field. Pumps called *brine-pumps* are put into communication with the lower part of the boiler, and so constructed as to draw the brine therefrom, and drive it into the sea. These brine-pumps are worked by the engine, and their operation is constant. The feed-pumps are likewise worked by the engine, and they bear such a proportion to the brine-pumps that the quantity of salt discharged in a given time in the brine is equal to the quantity of salt introduced in solution by the water of the feed-pumps. By this means the same actual quantity of salt is constantly maintained in the boiler, and consequently the strength of the solution remains invariable. If the brine discharged by the brine-pumps contains $\frac{5}{32}$ parts of salt, while the water introduced by the feed-pumps contains only $\frac{1}{32}$ part, then it is evident that five cubic feet of the feeding-water will contain no more salt than is contained in one cubic foot of brine. Under such circumstances the brine-pumps would be so constructed as to discharge $\frac{1}{5}$ of the water introduced by the feed-pumps, so that $\frac{4}{5}$ of all the water introduced into the boiler would be evaporated, and rendered available for working the engine.

To save the heat of the brine, a method has been adopted in the marine engines constructed by Messrs. Maudslay and Field, similar to one which has been long practised in steam-boilers, and in various apparatus for the warming of buildings. The current of heated brine is conducted from the boiler through a tube which is contained in another, through which the feed is introduced. The warm current of brine, therefore, as it passes out, imparts a considerable portion of its heat to the cold feed which comes in; and it is found that by this expedient the brine discharged into the sea may be reduced to a temperature of about 100°.

This expedient is so effectual, that when the apparatus is properly constructed, and kept in a state of efficiency, it may be regarded as nearly a perfect preventive against the incrustation, and the deposition of salt in the boilers, and is not attended with any considerable waste of fuel.

40. It is maintained by some practical men, that the economy of heat effected by brine-pumps, such as have been just described, is more than counterbalanced by the risk which attends them, if not accompanied by proper precautions. The pipes through which the salted water is discharged are, it is said, apt to get choked, in which case the pumps will necessarily cease to act, though they appear to the engineer to do so; and thus the water in the boiler may become salted to any extent without the knowledge of the engineer. When the process of *blowing out* is executed in the ordinary way, without brine-pumps, the engineer looks at his water-gauge and keeps the blow-off cock open, until the water level has fallen to the required point. Under these circumstances there is a certainty of having discharged from the boiler a certain quantity of salted water, a certainty which does not exist in the case of a continuous discharge of water by brine-pumps.

Such expedients, therefore, it is contended, should always be accompanied by some indicator, which shall show the degree of saltness of the water in the boiler, such as we shall presently explain.

41. In practice, if a marine boiler be regularly attended to, and the salted water be discharged either by the common method of blowing-off cocks or by brine-pumps, or any other expedient which shall impose the necessary limit on the degree of concentration of water in the boiler, the evil arising from incrustation will be quite inconsiderable.

A scale will in all cases be formed on the inner surface of the boilers, which must be removed from time to time when the vessel is in port. The best method of effecting this is by lighting some shavings, or other light and flaming combustible, in the furnaces when the boilers are empty and the safety-valves open. The expansion of the metal by the heat thus produced being greater than that of the matter composing the scale, the latter will be detached and will fall in pieces to the bottom of the boiler, from which it can be withdrawn with the water at the man-holes.

In some cases, however, it will be preferable to detach the scale by the hammer or chisel.

42. It is a great error to suppose that incrustation is either the

sole or principal cause of the rapid destruction of marine boilers. If it were so, it would necessarily happen that marine boilers in which expedients are adopted by which fresh water is used, or even those in which the process of blowing out has been regularly observed, and in which the scale is detached before it is allowed to thicken to an injurious extent, would last as long, or nearly as long, as land boilers. It is found, however, that the boilers in which these expedients are adopted with the greatest effect and regularity are, nevertheless, less durable in a very large proportion than land boilers. Thus, while a land boiler will last for twenty years, a marine boiler, similarly constructed, will, even with the greatest care, be worn out in four or five years.

The cause of this rapid destruction of the boiler is corrosion, but how this corrosion is produced is a question which has not hitherto been satisfactorily answered. It is contended that this is not to be ascribed to any chemical action of the sea water on the iron, inasmuch as the flues of marine boilers rarely show any deterioration from this cause, and even in worn-out marine boilers the hammer-marks on the flues are as conspicuous as when they are fresh from the boiler-maker. The thin film of scale which covers the interior surface would rather protect the iron from the action of the water. In fine, the seat of the corrosion is almost never those parts of the boiler which are in contact with the water. It is that part of the metal which includes the steam space that exhibits corrosion; but even there the effect is so irregular, that no data can be obtained by which the cause can be satisfactorily traced. The part which is most rapidly corroded in one boiler is not at all affected in another; and in some cases we find one side of the steam-chest attacked, the other side being untouched. Sometimes the iron exfoliates in flakes, while in others it appears as though it were eaten away by an acid.

43. In the application of the steam-engine to the propulsion of vessels in voyages of great extent, the economy of fuel acquires an importance greater than that which appertains to it in land engines, even in localities the most removed from coal-mines, and where its expense is greatest. The practical limit to steam voyages being determined by the greatest quantity of coals which a steam vessel can carry, every expedient by which the efficiency of the fuel can be increased becomes a means, not merely of a saving of expense, but of an increased extension of steam-power to navigation. Much attention has been bestowed on the augmentation of the duty of engines in the mining districts of Cornwall, where the question of their efficiency is merely a question of economy; but far greater care should be given to this subject, when the practicability of maintaining intercourse by steam

between distant points of the globe, will perhaps depend on the effect produced by a given quantity of fuel. So long as steam navigation was confined to river and channel transport and to coasting voyages, the speed of the vessel was a paramount consideration, at whatever expenditure of fuel it might be obtained; but since steam navigation has been extended to ocean voyages, where coals must be transported sufficient to keep the engine in operation for a long period of time without a fresh relay, greater attention has been bestowed upon the means of economising it.

Much of the efficiency of fuel must depend on the management of the fires, and therefore on the skill and care of the stokers. Formerly the efficiency of firemen was determined by the abundant production of steam; and so long as the steam was evolved in superabundance, however it might have blown off to waste, the duty of the stoker was considered as well performed. The regulation of the fires according to the demands of the engine was not thought of, and whether much or little steam was wanted, the duty of the stoker was to urge the fires to their extreme limit.

Since the resistance opposed by the action of the paddle-wheels of a steam-vessel varies with the state of the weather, the consumption of steam in the cylinders must undergo a corresponding variation; and if the production of steam in the boilers be not proportioned to this, the engines will either work with less efficiency than they might do under the actual circumstances of the weather, or more steam will be produced in the boilers than the cylinders can consume, and the surplus will be discharged to waste through the safety valves. The stokers of a marine engine, therefore, to perform their duty with efficiency, and obtain from the fuel the greatest possible effect, must discharge the functions of a self-regulating furnace, such as has been already described: they must regulate the force of the fires by the amount of steam which the cylinders are capable of consuming, and they must take care that no unconsumed fuel is allowed to be carried away from the ash-pit.

44. Formerly the heat radiated from every part of the surface of the boiler was allowed to go to waste, and to produce injurious effects on those parts of the vessel to which it was transmitted. This evil, however, has been removed by coating the boilers, steam-pipes, &c., of steam-vessels with felt, by which the escape of heat from the surface of the boiler is very nearly, if not altogether, prevented. This felt is attached to the boiler surface by a thick covering of white and red lead. This expedient was first applied in the year 1818 to a private steam vessel of Mr. Watt's, called the Caledonia; and it was subsequently adopted in another vessel, the machinery of which was constructed at Soho, called the James Watt.

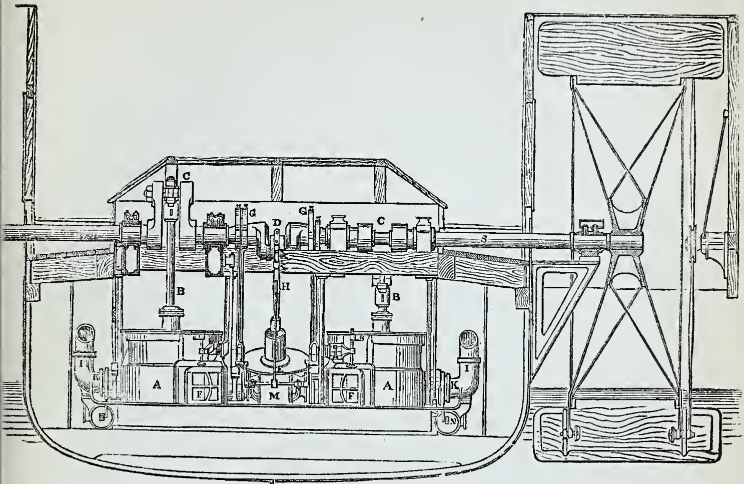


Fig. 10.

STEAM NAVIGATION.

CHAPTER III.

45. Economy of fuel.—46. Width and depth of furnace.—47. Advantage of expansive action.—48. Siamese engines.—49. Simplified arrangements.—50. Number and position of cylinders.—51. Proportion of diameter to stroke.—52. Oscillating engines.—53. Engines of the Peterhoff.—54. Propellers.—55. The common paddle-wheels.—56. Feathering paddles.—57. Morgan's paddle-wheel.—58. Field's split paddles.—59. American paddle-wheel.—60. Practical objections to feathering paddles.—61. Proportion of marine engines.—62. Submerged propellers.—63. Their disadvantages.—64. Screw-propellers.—65. Pitch and slip.—66. Manner of mounting screw-propellers.—67. Their various forms.

45. THE economy of fuel depends in a great degree on the arrangement of the furnaces, and the method of feeding them. In general, each boiler is worked by two or more furnaces communicating with the same system of flues. While the furnace

is fed, the door being open, a stream of cold air rushes in, passing over the burning fuel and lowering the temperature of the flues: this is an evil to be avoided. But, on the other hand, if the furnaces be fed at distant intervals, each furnace will be unduly heaped with fuel, a great quantity of smoke will be evolved, and the combustion of the fuel will be proportionally imperfect. The process of coking in front of the grate, which would insure a complete combustion of the fuel, has been already described in our tract on the Steam Engine. A frequent supply of coals, however, laid carefully on the front part of the grate, and gradually pushed backwards as each fresh feed is introduced, would require the fire door to be frequently opened, and cold air to be admitted. It would also require greater vigilance on the part of the stokers, than can generally be obtained in the circumstances in which they work. In steam-vessels the furnaces are therefore fed less frequently, fuel is introduced in greater quantities, and a less perfect combustion produced.

When several furnaces are constructed under the same boiler, communicating with the same system of flues, the process of feeding, and consequently opening one of them, obstructs the due operation of the others, for the current of cold air which is thus admitted into the flues checks the draught, and diminishes the efficiency of the furnaces in operation. It was formerly the practice in vessels exceeding one hundred horse-power, to place four furnaces under each boiler, communicating with the same system of flues. Such an arrangement was found to be attended with a bad draught in the furnaces, and therefore to require a greater quantity of heating surface to produce the necessary evaporation. This entailed upon the machinery the occupation of more space in the vessel in proportion to its power; it has therefore been more recently the practice to give a separate system of flues to each pair of furnaces, or, at most, to every three furnaces. When three furnaces communicate with a common flue, two will always be in operation, while the third is being cleared out; but if the same quantity of fire were divided among two furnaces, then the clearing out of one would throw out of operation half the entire quantity of fire, and during the process the evaporation would be injuriously diminished.

46. It is found by experience, that the side plates of furnaces are liable to more rapid destruction than their roofs, owing, probably, to a greater liability to deposit. Furnaces, therefore, should not be made narrower than a certain limit. Great depth from front to back is also attended with practical inconvenience, as it renders firing tools of considerable length, and a corresponding extent of stoking room necessary. It is recommended by those who have had

much practical experience in steam-vessels, that furnaces six feet in depth from front to back should not be less than three feet in width to afford means of firing with as little injury to the side plates as possible, and of keeping the fires in the condition necessary for the production of the greatest effect. The tops of the furnaces scarcely ever decay, and are seldom subject to an alteration of figure, unless the level of the water be allowed to fall below them.

47. The method by which the greatest quantity of practical effect can be obtained from a given quantity of fuel must, however, mainly depend on the extended application of the expansive principle. This has been the means by which an extraordinary amount of duty has been obtained from the Cornish engines. The difficulty of the application of this principle in marine engines, has arisen from the objections entertained in Europe to the use of steam of high-pressure, under the circumstances in which the engine must be worked at sea. To apply the expansive principle, it is necessary that the moving power at the commencement of the stroke shall considerably exceed the resistance, its force being gradually attenuated till the completion of the stroke, when it will at length become less than the resistance. This condition may, however, be attained with steam of limited pressure, if the engine be constructed with a sufficient quantity of piston surface.

48. This method of rendering the expansive principle available at sea, and compatible with low-pressure steam, was projected and executed by Messrs. Maudslay and Field. Their improvement consists in adapting two steam cylinders in one engine, in such a manner that the steam shall act simultaneously on both pistons, causing them to ascend and descend together. The piston-rods are both attached to the same horizontal cross-head, whereby their combined action is applied to one crank by means of a connecting-rod placed between the pistons.

A section of such an engine (which has been called the Siamese engine), made by a plane passing through the two piston-rods P P′ and cylinders, is represented in fig. 9. The piston-rods are attached to a cross-head C, which ascends and descends with them. This cross-head drives upwards and downwards an axle D, to which the lower end of the connecting-rod E is attached. The other end of the connecting-rod drives the crank-pin F, and imparts revolution to the paddle-shaft G. A rod H conveys motion by means of a beam I to the rod K of the air-pump L.

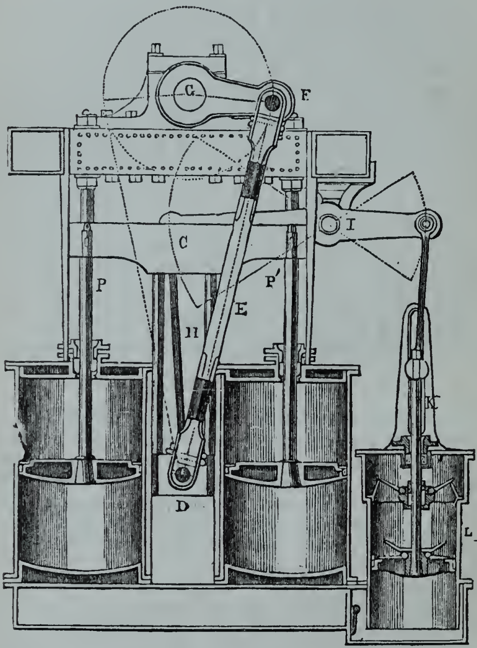
Engines constructed on this principle were applied in several steamers, and amongst others in her Majesty's steam-frigate "Retribution."

49. Within the last ten or fifteen years, and especially since the more general adoption of the screw-propeller, the marine engine has been greatly simplified in its mechanical arrangements. Its bulk has thus been diminished, as well as

the cost of construction; and the profitable tonnage of the vessel has been increased in a corresponding proportion. The beam and its appendages have been very generally laid aside, and the piston-rods have been more directly connected with the cranks.

In some cases the piston-rods are kept in their direction by guides, and their rectilinear motion is accommodated to the

Fig. 9.



rotation of the cranks by connecting-rods, which consequently have an oscillation between the extreme points of the play of the cranks.

In other cases the cylinders themselves receive this oscillation. In such cases the connecting-rods are dispensed with, and the ends of the piston-rods are immediately jointed to the cranks. The oscillation of the piston causes the motion of the valves necessary for the alternate admission and escape of the steam on the one and the other side of the piston.

50. The number of cylinders varies, being generally two, but

sometimes three, sometimes four, and sometimes, though very exceptionally, only one.

The position of the cylinders is subject to great variation. They are placed with their axes sometimes vertical, sometimes horizontal, and sometimes oblique.

51. The proportion of the diameter to the stroke is subject to like variation. The general tendency has been to increase the relative magnitude of the diameter, which in recently built engines is sometimes more than twice the stroke, and rarely less than two-thirds of it. Thus in the engines of the "Niger," constructed by Messrs. Maudslay and Field, the cylinders have 48 inches diameter, with only 22 inches stroke; and in the "Simoom," by Boulton and Watt, they have 44 inches diameter, with 30 inches stroke.

The object of shortening the stroke is to diminish the momentum of the piston, of which the motion requires to be so frequently reversed.

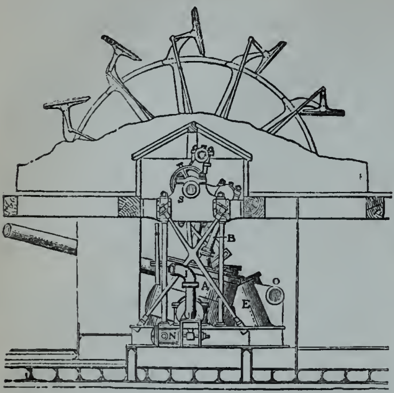
52. In engines constructed on the oscillating principle, the top of the piston-rod is coupled with the crank, and the piston-rod moves backward and forward in the direction of the axis of the cylinder, while its extremity revolves in a circle with the crank. It is therefore necessary that the cylinder should oscillate from side to side, to accommodate the motion of the piston-rod to that of the crank. For this purpose the cylinder is provided on each side with a short hollow pivot or trunnion, on which it swings; and through one of these trunnions the steam enters the cylinder from the boiler, while it escapes through the other to the condenser. The alternate admission and escape of steam on the one side and the other of the piston, is regulated by a valve attached to the cylinder and swinging with it. In the larger class of engines, however, two valves are usually employed for this purpose, and are so arranged as to balance one another.

Oscillating engines are usually placed immediately under the cranks, and occupy no greater length in the vessel than the diameter of the cylinder. On the shaft which connects the engine, called the intermediate shaft, a crank is forged which in its revolutions gives motion to the piston of the air-pump.

53. The arrangements generally employed at present in the most improved vessels propelled by oscillating engines, will be understood by reference to fig. 10, which represents the transverse section of the steam-yacht "Peterhoff," constructed for the Emperor of Russia, by Messrs. Rennie, and fig. 11, which is a side view of the engines of the same vessel. These figures are copied with the permission of the publishers and the authors, from the article on the steam-engine, in the last edition of Brande's "Dictionary of Science." A, A are the cylinders; B, B are the piston-rods, which are connected immediately with the cranks C, C; D is a crank on

the intermediate shaft for working the piston of the air-pump E; F, F are the slide-valves, by which the admission of the steam to the cylinders is regulated; G, G are double eccentrics on the intermediate shaft, whereby the valves F, F are moved; H is a handle, whereby the engines may be stopped, started, or reversed; I, I are the steam-pipes leading to the steam-trunnions K, K, on which, and on other trunnions, connected with the pipe M, the cylinders oscillate; N, N are pumps, the pistons of which are attached to the trunnions, and are worked by the oscillation of the cylinders; O is the waste-water pipe, through which the water which has accomplished the function of condensing the steam is ejected over-board. The same letters refer to the same parts in the two figures.

Fig. 11.

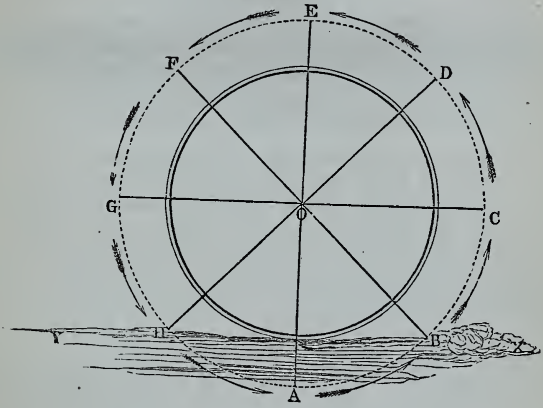


54. To obtain from the moving power its full amount of mechanical effect in propelling the vessel, it would be necessary that it should constantly act against the water in a horizontal direction, and with a motion contrary to the course of the vessel. No system of propellers has, however, yet been contrived capable of perfectly accomplishing this. Patents have been granted for many ingenious mechanical combinations to impart to the propelling surfaces such angles as appeared to the respective contrivers most advantageous. In most of these the mechanical complexity has formed a fatal objection. No part of the machinery of a steam-vessel is so liable to become deranged at sea as the propellers; and, therefore, that simplicity of construction which is compatible with those repairs which are possible on such emergencies is quite essential for safe practical use.

55. The ordinary paddle-wheel, as has been already stated, is a wheel revolving upon a shaft driven by the engine, and carrying upon its circumference a number of flat boards, called paddle-boards, which are secured by nuts and braces in a fixed position; and that position is such that the planes of the paddle-boards diverge from the centre of the shaft on which the wheel turns. The consequence of this arrangement is that each paddle-board can only act in that direction which is most advantageous for the propulsion of the vessel when it arrives at the lowest point of the wheel. In fig. 12, let O be the shaft on which the common paddle-wheel revolves; the positions of the paddle-boards are represented at A, B, C, &c.; X Y represents the water-line, the course of the vessel being supposed to be from X to Y; the arrows represent the direction in which the paddle-wheel

revolves. The wheel is immersed to the depth of the lowest paddle-board, since a less degree of immersion would render a portion of the surface of each paddle-board mechanically useless. In the position A, the whole force of the paddle-board is efficient for propelling the vessel; but as the paddle enters the water in the position H, its action upon the water not being horizontal, is only partially effective for propulsion : a part of the force which drives the paddle is expended in depressing the water, and the remainder in driving it contrary to the course of the vessel, and, therefore,

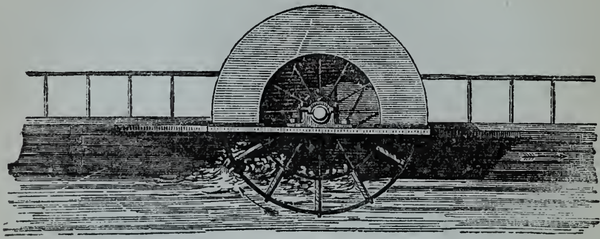
Fig. 12.



by its re-action producing a certain propelling effect. The tendency, however, of the paddle entering the water at H is to form a hollow or trough, which the water, by its ordinary property, has a continual tendency to fill up. After passing the lowest point A, as the paddle approaches the position B, where it emerges from the water, its action again becomes oblique, a part only having a propelling effect, and the remainder having a tendency to raise the water, and throw up a wave and spray behind the paddle-wheel. It is evident that the more deeply the paddle-wheel becomes immersed, the greater will be the proportion of the propelling power thus wasted in elevating and depressing the water; and if the wheel were immersed to its axis, the whole force of the paddle-boards, on entering and leaving the water, would be lost, no part of it having a tendency to propel. If a still deeper immersion take place, the paddle-boards above the axis would have a tendency to retard the course of the vessel. When the vessel is, therefore, in proper trim, the immersion should not exceed nor fall short of the depth of the lowest paddle; but for various reasons it is impossible in practice to maintain this fixed immersion : the agitation of the surface of the sea causing the vessel to roll, will necessarily produce a great variation in the immersion of the paddle-wheels, one becoming frequently immersed to its axle, while the other is raised altogether out of the water. Also the draught of water of the vessel is liable to change, by the variation in the cargo; this will necessarily happen in steamers which take long voyages. At starting they are heavily laden with fuel, which as they proceed is gradually consumed, whereby the vessel is lightened.

56. To remove this defect, and economise as much as possible the propelling effect of the paddle-boards, it would be necessary so to construct them that they may enter and leave the water edgeways,

Fig. 13.



or as nearly so as possible; such an arrangement would be, in effect, equivalent to the process called feathering, as applied to oars. Any mechanism which would perfectly accomplish this would cause the paddles to work in almost perfect silence, and would very nearly remove the inconvenient and injurious vibration which is produced by the action of the common paddles. But the construction of feathering paddles is attended with great difficulty, under the peculiar circumstances in which such wheels work. Any mechanism so complex that it could not be easily repaired when deranged, with such engineering implements and skill as can be obtained at sea, would be attended with great objections.

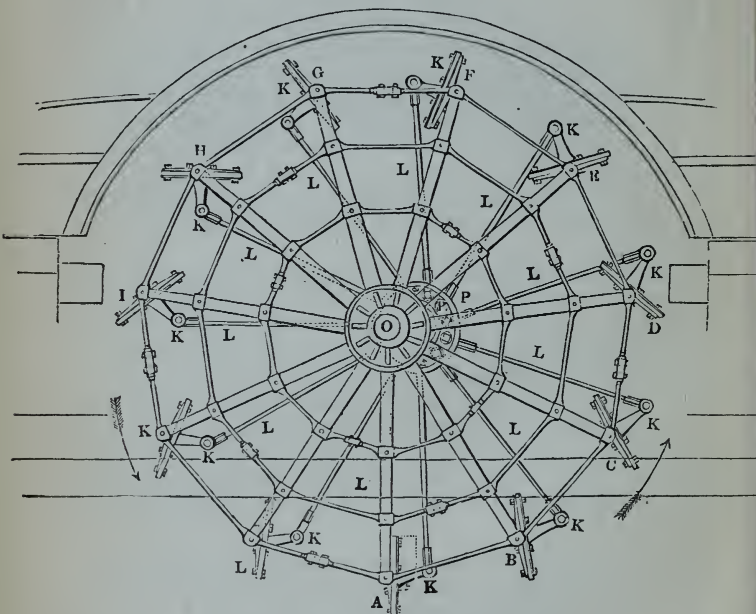
Feathering paddle-boards must necessarily have a motion independently of the motion of the wheel, since any fixed position which could be given to them, though it might be most favourable to their action in one position, would not be so in their whole course through the water. Thus the paddle-board when at the lowest point should be in a vertical position, or so placed that its plane, if continued upwards, would pass through the axis of the wheel. In other positions, however, as it passes through the water, it should present its upper edge, not towards the axle of the wheel, but towards a point above the highest point of the wheel. The precise point to which the edge of the paddle-board should be directed is capable of mathematical determination. But it will vary according to circumstances, which depend on the motion of the vessel. The progressive motion of the vessel, independently of the wind or current, must obviously be slower than the motion of the paddle-boards round the axle of the wheel; since it is by the difference of these velocities that the re-action of the water is produced, by which the vessel is propelled. The proportion, however, between the progressive speed of the vessel and the rotative speed of the paddle-boards is not fixed; it will vary with the shape and structure of the vessel, and with its depth of immersion; nevertheless it is upon this proportion that the manner in which the paddle-boards should shift their position must be determined. If the progressive speed of the vessel were nearly equal to the rotative speed of the paddle-boards, the latter should so shift their position that their upper edges should be presented to a point very little above the highest point of the wheel. This is a state of things which could only take place in the case of a steamer of a small draught of water, shallop-shaped, and so constructed as to suffer little resistance from the fluid. On the other hand, the greater the depth of immersion, and the less fine the lines of the vessel, the greater will be the resistance in passing through the water, and the greater will be the proportion which the rotative speed of the paddle-boards will bear to the progressive speed of the vessel. In this latter case the independent motion of the paddle-boards should be such that their edges, while in the water, shall be presented towards a point considerably above the highest point of the paddle-wheel.

A vast number of ingenious mechanical contrivances have been invented and patented, for accomplishing the objects just explained. Some of these have failed from the circumstance of their inventors not clearly understanding what precise motion it was necessary to impart to the paddle-boards; others have failed from the complexity of the mechanism by which the desired effect was produced.

57. One of these contrivances of late construction is represented in fig. 11, being the paddle-wheel of the Russian steamer "Peterhoff." To convey a general idea of the feathering principle, however, we have represented in fig. 14 the form of wheel known as Morgan's paddle-wheel.

This contrivance may be shortly stated to consist in causing the wheel which bears the paddles to revolve on one centre, and the radial arms which move the paddles to revolve on another centre. Let A B C D E F G H I K L be the polygonal circumference of the paddle-wheel, formed of straight bars, securely connected together at the extremities of the spokes or radii of the wheel which turns on the shaft which is worked by the engine; the centre of this wheel being at O. So far this wheel is similar to the common paddle-wheel; but the paddle-boards are not, as in the common wheel, fixed at A B C, &c., so as to be always directed to the centre O, but are so placed that they are capable of turning on axles which are always horizontal, so that they can take any angle with respect to the water which may be given to them. From the centres, or the line joining the pivots on which these paddle-boards turn, there proceed short arms K, firmly fixed to the paddle-boards at an angle of about 120°. On a motion given to this arm K, it will therefore give a corresponding angular motion to the paddle-board, so as to make it turn on its pivots. At the extremities of the several arms marked K is a pin or pivot, to which the extremities of the radial arms L are severally attached, so that the angle between each radial arm L and the short paddle arm K is capable of being changed by any motion imparted to L; the radial arms are connected at the other end with a centre, round which they are capable of revolving. Now, since the points A B C, &c., which are the pivots on which the paddle-boards turn, are moved in the circumference of a circle, of which the centre is O, they are always at the same distance from that point, consequently they will continually vary their distance from the other centre P. Thus, when a paddle-board arrives at that point of its revolution at which the centre

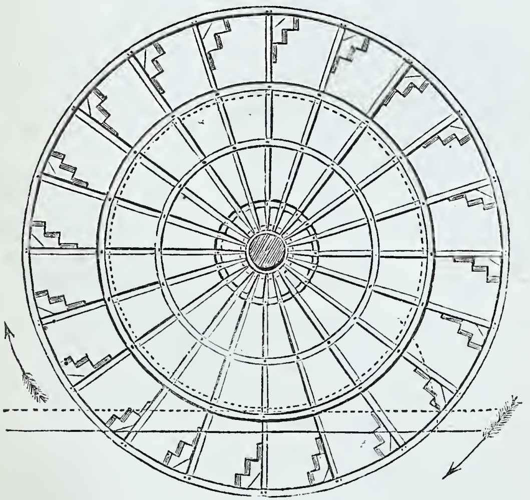
Fig. 14.



round which it revolves lies precisely between it and the centre O, its distance from the former centre is less than in any other position. As it departs from that point, its distance from that centre gradually increases until it arrives at the opposite point of its revolution, where the centre O is exactly between it and the former centre; then the distance of the paddle-board from the former centre is greatest. This constant change of distance between each paddle-board and the centre P is accommodated by the variation of the angle between the radial arm L and the short paddle-board arm K: as the paddle-board approaches the centre P, this gradually diminishes; and as the distance of the paddle-board increases, the angle is likewise augmented. This change in the magnitude of the angle, which thus accommodates the varying position of the paddle-board with respect to the centre P, will be observed in the figure. The paddle-board D is nearest to P; and it will be observed that the angle contained between L and K is there very acute; at E the angle between L and K increases, but is still acute; at G it increases to a right angle; at H it becomes obtuse; and at K, where it is most distant from the centre P, it becomes most obtuse. It again diminishes at L, and becomes a right angle between A and B. Now this continual shifting of the direction of the short arm K is necessarily accompanied by an equivalent change of position in the paddle-board to which it is attached; and the position of the second centre P is, or may be, so adjusted that this paddle-board, as it enters the water and emerges from it, shall be such as shall be most advantageous for propelling the vessel, and therefore attended with less of that vibration which arises chiefly from the alternate depression and elevation of the water, owing to the oblique action of the paddle-boards.

58. *Field's split paddles.*—In the year 1833, Mr. Field, of the firm of Maudslay and Field, constructed a paddle-wheel with fixed paddle-boards, but each board being divided into several narrow slips arranged one a little behind the other, as represented in fig. 15. These divided boards he pro-

Fig. 15.



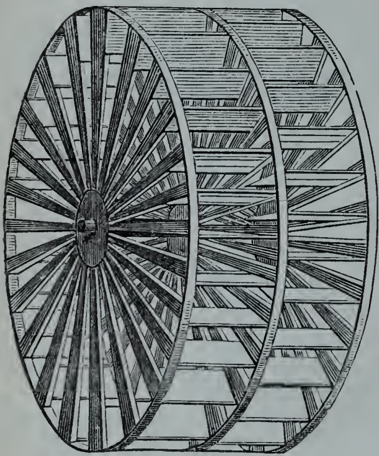
posed to arrange in such cycloidal curves that they must all enter the water at the same place in immediate succession, avoiding the shock produced by the entrance of the common board. These split paddle-boards are as efficient in propelling when at the lowest point as the common paddle-boards, and, when they emerge, the water escapes simultaneously from each narrow board, and is not thrown up, as is the case with common paddle-boards.

The number of bars, or separate parts into which each paddle-board is divided, has been very various. When first introduced, each board was divided into six or seven parts: this was subsequently reduced; and in the wheels of this form constructed for the government vessels, the paddle-boards consist only of two parts, coming as near to the common wheel as is possible, without altogether abandoning the principle of the split paddle.

59. The paddle-wheels generally used in American steam-boats are formed, as if by the combination of two or more common paddle-wheels, placed one outside the other, on the same axle, but so that the paddle-boards of each may have an intermediate position between those of the adjacent one, as represented in fig. 16.

The spokes, which are bolted to cast-iron flanges, are of wood. These flanges, to which they are so bolted, are keyed upon the paddle-shaft. The outer extremities of the spokes are attached to circular bands or hoops of iron, surrounding the wheel; and the paddle-boards, which are formed of hard wood, are bolted to the spokes. The wheels, thus constructed, sometimes consist of three, and not unfrequently four, independent circles of paddle-boards, placed one beside the other, and so adjusted in their position, that the boards of no two divisions shall correspond.

Fig. 16.



The great magnitude of the paddle-wheels, and the circumstance of the navigation being carried on, for the most part, in smooth water, have rendered unnecessary, in America, the adoption of any of those expedients for neutralising the effects of the oblique action of the paddles, which have been tried, but hitherto with so little success, in Europe.*

60. The practical objections to the use of the feathering principle in general, go far to balance the advantages attending them. According to Mr. Bourne, whose skill and experience on this subject entitle his opinion to the highest respect, all expedients of this class are expensive, both to make and maintain. The wear and friction in such a multitude of joints is very considerable; and if any of the arms get adrift, or break, they will be whirled round like a flail, and may perhaps cut through the paddle-box, or even the vessel. If the injury be of such a nature that the wheels cannot be turned round (and this has sometimes happened), it will follow that the engines will be virtually disabled until the obstruction can be cleared away; and if the weather be very stormy, or the vessel be in a critical situation,

* For a notice of the inland steam navigation of the United States, see "Railway Economy," chap. xvi. Also "Museum of Science and Art," vol. ii. p. 17.

she may be lost in consequence of her temporary derangement. Upon the whole, therefore, the application of feathering wheels to vessels intended to perform long voyages through stormy seas, appears to be of doubtful propriety. For channel trips, and in situations where the wheels can be carefully examined at short intervals, the risk is not so great; but in that case nearly the same benefits will be attained by increasing the length of the paddle-floats, and giving the wheels less dip. There is no material difference between the performance of a feathering wheel and that of a radial wheel, if the two wheels be of the same diameter, and if they have both a light dip with long narrow floats. And, as in sea-going vessels, the wheels must necessarily be of considerable diameter, and as there is nothing to prevent the other circumstances conducive to efficiency from being observed, it follows that in ocean-vessels radial wheels would be about as efficient as feathering wheels, but for the circumstance of a variable immersion. It is not necessary, however, that there should be much variation in the immersion if large vessels be employed, or if coal is more frequently taken on board during the voyage; and as neither of these alternatives is attended with the risk incident to the use of feathering wheels, they appear to be entitled to that preference which ultimately they are likely to obtain.

61. In oscillating engines the piston-rod is usually made one-ninth of the diameter of the cylinder, and the crank-pin is made about one-seventh of the diameter of the cylinder. The diameter of the paddle-shaft must have reference not merely to the diameter of the cylinder, but also to the length of the stroke of the piston, or, what is the same thing, to the length of the crank. If the square of the diameter of the cylinder in inches be multiplied by the length of the crank in inches, and the cube-root of the product be extracted, then that root multiplied by ·242 will give the diameter proper for the shaft in inches at the smallest part. The diameter of the trunnions is regulated by the diameter of the steam and eduction pipes, and these are each usually about one-fifth of the diameter of the cylinder; but it is better to make the steam trunnions a little less, and the eduction trunnions a little more, than this proportion. The steam and eduction pipes, where they enter their respective trunnions, are kept tight by a packing of hemp, which is compressed by a suitable ring or gland, tightened by screws. In land engines the air-pump and condenser are each made about one-eighth of the capacity of the cylinder, but in marine engines they are made somewhat larger.

62. Submerged propellers, whatever be their form, are exempt from many of the disadvantages which are common to every species of paddle-wheel. It will be evident that the effect of

such a propeller will be nearly the same, whatever position may be given to it in the water. However the ship may pitch or roll, or however unequal the surface of the sea may be, such a propeller will always produce the same backward current without any variation of effect.

The circumstances which prevent the co-operation of the power of steam with that of the sails in steam-vessels propelled by the common paddle-wheels, will not operate with submerged propellers, inasmuch as their effect is altogether independent of the careening of the ship.

63. But though this defect is remedied, the submerged propellers in general are still subject to objections, to which even the common paddle-wheel is not obnoxious. Being permanently submerged and liable to accident, fracture, and derangement from various causes, they are inaccessible, and cannot be repaired at sea. But, besides this, when the object in view is to take full advantage of the power of the sails at times when it is expedient to suspend the action of the machinery, the submerged propeller becomes an obstruction, more or less considerable, to the progress of the vessel. Various expedients have been contrived, and in some instances practically applied, by which the propeller can be lifted out of the water when it is not in operation, but hitherto this has not been found practically convenient, at least for commercial vessels, though sometimes adopted for vessels of war.

64. The screw-propeller is similar in form and mechanical principle to the hydraulic machine known as the screw of Archimedes. A cylinder placed at the bottom of the vessel, and in the direction of the keel, is surrounded by a spiral blade similar, precisely, to the thread of a common screw, but projecting from it instead of being cut into its surface. If such a screw were turned in a solid, it would move forward through a space equal to the distance between two contiguous threads in each revolution; but the water, not being solid, yields more or less to the re-action of the screw, and consequently the screw moves forward through a space in each revolution less than the distance between two contiguous threads.

65. The distance between two contiguous threads is technically called the *pitch* of the screw; a term, however, which is sometimes also used to express the angle formed by the blade of the screw with its axis, such angle supplying the means of calculating the distance between such contiguous threads. We shall here, however, use the term pitch in the former sense. The difference between the pitch of the screw and the space through which the screw actually progresses in the water in one revolution is called the *slip*.

In the first vessels to which screw-propellers were applied, the screw consisted of a single spiral blade, which made one convolution only round the cylinder. This arrangement was subsequently modified, and two convolutions and a half of a double-threaded screw were used instead of one complete convolution of a single-threaded screw. This plan has been occasionally varied, a smaller fraction of a convolution being sometimes used.

It is found in practice that the amount of the slip in general varies from one-tenth to one-twentieth of the pitch; that is to say, the actual velocity of the screw through the water is from one-tenth to one-twentieth less than it would be if the screw worked through a solid, or as an ordinary screw in its nut.

66. The screw-propeller is usually fixed upon an axis parallel to the keel of the vessel, and mounted in a space in the dead wood between the stern-post and rudder-post. It is usually suspended on a short shaft, carried by a metal frame, having a rack on each side, in which endless screws work, by means of which the frame supporting the propeller can be lifted out of the water, so that the screw can be repaired if required or a new one introduced without putting the vessel into dock.

To enable the water to react in a manner analogous to that in which the nut reacts upon the common screw, the thread requires to be much deeper than if the screw worked in metal or wood, and the pressing surface to be proportionally larger. Accordingly screw-propellers are always made with much smaller central bodies, and a much deeper thread than the common screw. They are also made as large as possible in diameter, extending generally from the keel to a point nearly level with the surface of the water. Thus the diameter of the screw is little less than the draft of the vessel.

67. To convey some idea of the forms of screw-propellers, we have represented in the annexed figures the forms of some of the propellers most generally adopted.

In fig. 17 is represented a perspective view of Smith's screw-propeller, with two threads or blades, as finally adopted in her Majesty's steamer

Fig. 17.

Fig. 18.

Fig. 19.

Fig. 20.

"Rattler." This is the form of the screw now most generally adopted in the

British navy. An end view or an elevation looking against the end of the shaft is shown in fig. 18. Smith's three-thread screw differs from this only in having three arms instead of two.

Fig. 21.

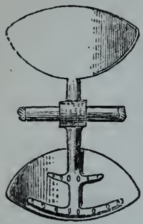


Fig. 22.

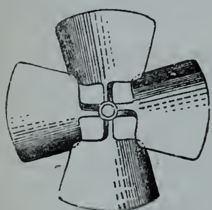
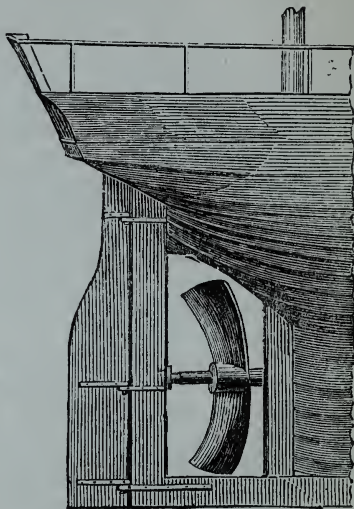


Fig. 23.



Strimman's propeller is shown by an end view in fig. 19, and a side view in fig. 20.

Sunderland's propeller, as applied in the "Rattler," is shown in fig. 21, consisting of two flat plates, set upon arms, fixed to an axis revolving beneath the water in the stern. In the "Rattler," this propeller was placed in the stern in the dead wood, instead of projecting out behind the rudder as in the Sunderland arrangement.

In fig. 22 is represented Woodcroft's propeller, also applied in the "Rattler." This has four arms or blades, and the pitch of the screw at its leading edge is less than the pitch at its terminal edge.

In fig. 23 * is represented, as set in the stern of the vessel, the form of Hodson's screw, from which excellent results are said to have been obtained. This form of screw has been much used in France, Holland, and other countries of the continent; and in some cases in which the common screw has been superseded by a screw of this description, an improvement has been obtained in the speed amounting to about a knot an hour. Such results will only ensue when the original screw has been of inadequate dimension, so that the loss by slip has been large in amount, and the more the slip is reduced, the less will become the advantage of any deviation from Smith's form of screw with uniform pitch.†

* Figs. 17 to 23 have been taken with the permission of the author from Mr. Bourne's work "on the Screw-propeller."

† Bourne "on the Screw-propeller," p. 136.

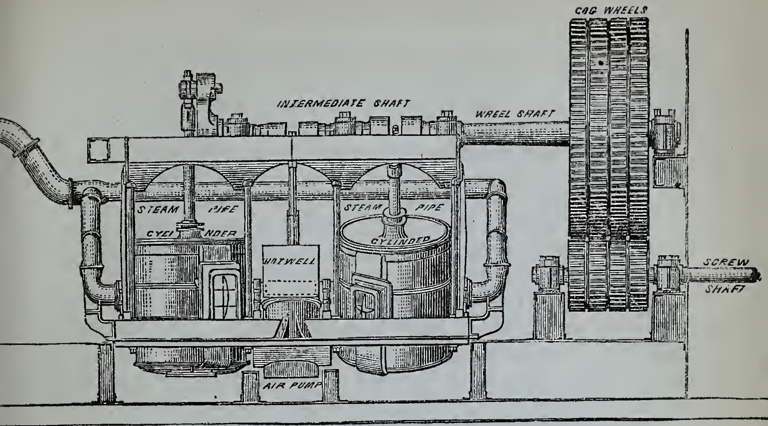


Fig. 26.

STEAM NAVIGATION.

CHAPTER IV.

68. Effect of the screw-propeller reaction on the vessel.—69. Their best practical proportion.—70. Their varying pitch.—71. Relative advantages of screw and paddle-wheels.—72. Their effects in long sea-voyages. —73. Experiments with the "Rattler" and "Alecto."—74. These experiments continued.—75. Admiralty experiments.—76. Government report.—77. Application of the screw in the commercial marine. —78. Application of screw to mail-vessels.—79. Geared and direct action.—80. Geared-engines.—81. Fairbairn's internal gearing.—82. Subdivision of the power among several cylinders.—83. Protection from shot.—84. Regulation of slides.—85. Relative speed of screw and vessel.—86. Engines of the "Great Britain."—87. Engines of the "Arrogant" and "Encounter."—88. Various forms of screw-engines. —89. Cross action of H. M.'s screw steam-packet "Plumper."— 90. Auxiliary steam-power.—91. Effect of screw-vessels head to wind.—92. Nominal and real horse-power.—93. Official tables of the strength of the steam-navy.

68. THE screw, whatever be its form or structure, in driving the water sternwards, sustains a corresponding reaction which takes effect upon the screw-shaft, and produces an equivalent pressure on its bearing to its anterior extremity. The force of this forward thrust of the screw-shaft, combined with its velocity of rotation, produced, in the earlier screw-vessels, considerable inconvenience in consequence of the friction attending it, and several cases

occurred where the end of the shaft being rendered white-hot was actually welded to the steel plate against which it pressed, although a stream of water was continually running over the surface in contact. Various expedients have since then been proposed for remedying this inconvenience. One of these was to let the end of the shaft enter a tight cylinder of oil in the manner of a piston, so that it would press against a liquid instead of a solid. Another was to place a large collar upon the shaft which should press against a number of balls or small rollers like those of a swivel-bridge. Neither of these plans, however, appears to have been so successful as to get into general use, and one or other of the following expedients is now generally adopted. The thrust of the screw-shaft is received either upon a number of collars or a series of discs placed at the end of the shaft and resting on a cistern of oil which is usually cast upon the base plate or some solid part of the engine, and its end is sufficiently strong to bear the thrust of the screw. Interposed, however, between the end of the cistern and that of the shaft are two, three, or more discs of metal, generally two inches thick, and having diameters equal to that of the shaft. A bolt passes through their centre to keep them in line, but they are each free to revolve in the bolt, and where the shaft passes out of the cistern a collar of leather is applied to prevent the oil from escaping. It will be obvious from such an arrangement that if the end of the shaft which it presses upon the discs begins to heat from undue friction, it will revolve with somewhat more difficulty, and will consequently carry the first disc round with it. The rubbing surfaces are therefore no longer at the end of the shaft, but at the first disc and the second disc. In fact the rubbing surfaces, instead of being limited to a single disc, are distributed over several. Those surfaces which begin to heat, and consequently to stick, will cease to rub, whereby they will speedily become cool again and their efficiency consequently be restored. (See Mr. Bourne's article on the "Screw-Propeller" in the Appendix to Brande's "Dictionary of Science and Art.")

69. According to the same authority the best practical proportion and form of screw-propellers for mercantile vessels are as follows. Those of three blades are on the whole preferable. The diameter should be as large as possible. When the area of the circle described by the extremity of the arms of the screw has one square foot for every two-and-a-half square feet in the area of the midship section immersed, a very efficient performance is obtained. The pitch of the screw should be equal to its diameter, or perhaps a little exceed it, and the length measured parallel to its shaft should be about one-sixth of a convolution. Thus, for

example, in the case of a screw 12 feet in diameter, the pitch would be from 12 to 14 feet, and the length about 2 feet.

70. Screws are generally made with one uniform pitch, and their blades are set at right angles to the shaft. A gradual increase of pitch towards the leading end of the screw is, however, recommended. Thus, the pitch of the centre should be about 10 per cent. less than at the circumference, for the centre should merely screw through the water, without producing any reaction or propelling force. The efficient part being near the circumference, it is also recommended that the blades, instead of being precisely perpendicular to the shaft, should be inclined a little sternwards, so as to produce a tendency in the water which they drive backwards to converge to a point. It is assumed that this convergent tendency may balance the divergent tendency due to the centrifugal force attending the revolution: so that the two forces being in equilibrium will cause the water to be projected backwards from the screw in a cylindrical column. In the case of the ordinary screw, with blades at right angles to the shaft, the water projected backwards assumes the figure of the frustum of a cone, and a certain proportion of the power is thereby lost.

71. The relative advantages of screw and paddle-propellers depend in a great degree upon the immersion. It appeared from experiments made on a considerable scale with steamers of the Royal Navy, that in deep immersion the screw has an advantage over the paddle-wheel of one-and-a-half per cent.; but that, with medium immersion, the paddle-wheel had an advantage of one-and-three-quarters per cent. over the screw, an advantage which was augmented to four-and-three-quarters per cent. for light immersions. It appears, therefore, that the screw-propeller has a certain advantage over the paddle when the vessel is deep in the water, and that, on the other hand, the paddle gains an advantage over the screw in proportion as the immersion is less.

72. In long sea voyages, where the immersion is liable to considerable variation by reason of the lightening of the vessel owing to the consumption of the fuel, the screw will have the advantage over the paddle in the commencement of the voyage, and the paddle over the screw towards the end of it. In rough weather, where, by the rolling and pitching of the vessel, the paddle-wheels are liable at one time to be deeply plunged in the water, and at another to be raised out of it, the screw will have an obvious advantage.

73. In his work upon the screw-propeller, Mr. Bourne has given the details of a series of important experiments made with H. M. steamers "Rattler" and "Alecto," to determine the relative advantages of screw and paddle-wheels against a head wind. The result of these experiments seemed to prove, that

under such conditions the screw is less efficient than the paddle; for though both vessels attained the same speed of four knots against a strong head wind, yet, in the case of the "Alecto," this performance was attained with a velocity of the engine of 12 strokes per minute, whereas in the "Rattler" it was only attained with a velocity of the engine of 22 strokes per minute. It follows, therefore, that a screw-vessel in proceeding head to wind will require 1·8 times, or nearly twice the quantity of fuel to do the same amount of work. The screw, in fact, revolves at nearly the same velocity whether the wind is adverse or favourable, or whether the vessel is lying at anchor; and this is a serious defect in the case of vessels intended to encounter adverse winds. In the case of vessels, however, which use the screw only as a resource in calms, or as an auxiliary to the sails, this disadvantage will not be experienced, since such vessels have no pretensions to the capability of proceeding in direct opposition to a strong head wind.

74. Among the experiments made with the "Alecto" and "Rattler," some of the most interesting and important were directed to the determination of the relative towing powers of the screw and paddle-wheel. For this purpose the two ships were lashed stern to stern, and the engines of both were set to work so as to make them draw the connecting chain in opposite directions. In these and all other cases where screw and paddle-vessels of equal power and size have been thus connected, the screw-vessel has preponderated, and towed the paddle-vessel as soon as the engines were set to work.

When the "Rattler" and "Alecto" were lashed together in this manner, the "Alecto's" engines were set on first, and she was allowed to tow the "Rattler" at the rate of two knots an hour. The "Rattler's" engines were then set on. In five minutes the two vessels became completely stationary. The "Rattler" then began to move ahead, and towed the "Alecto" against the whole force of her engines, at the rate of 2·8 knots per hour. In like manner the "Niger" towed the "Basilisk" astern, in opposition to the force of her engines at the rate of 1·1 knots per hour. The natural inference from this experiment would be that the screw is more suitable for towing than the paddle; yet this inference is not confirmed by the experiment, for when the "Niger" and "Basilisk" were each set to tow the other alternately, in the usual manner in which a steamer tows a ship, it was found that the "Niger" towed the "Basilisk" at a speed of 5·63 knots, with 593·9 horse-power, and that the "Basilisk" towed the "Niger" at the rate of 6 knots, with 572·3 horse-power. The paddle-vessel, therefore, accomplished in towing the largest speed with the least power. It has also been found that when a paddle and screw-vessel set stern to stern push one another instead of pulling one another, the paddle-vessel preponderates, whereas, if they pull, the screw-vessel preponderates. These circumstances seem to show that the power of a screw-vessel to tow a paddle-vessel astern, when the two are tied together, does not arise from any superior tractive efficacy of the screw itself, but is due to the centrifugal action of the screw, which raises the level of the water at the stern, so that the vessel gravitates down an inclined plane.*

75. The first experiments tried by the Admiralty with the screw-propeller were made in 1840-41; and in the next three years, 1842-44, eight screw vessels were built. This number was augmented by twenty-six in 1845. In 1848 there were not less than forty-five government screw-steamers afloat; and since that time, and more especially since the commencement of the war with Russia, the increase of the screw-steam navy has gone on at a rate which justifies the conclusion that ere long no vessel of war, of whatever class, in the British navy will be unprovided with the power, to a greater or less extent, of steam propulsion.

76. In a government official report of the results of various trials of the performance of screw-steamers, dated so far back as May 1850, before that propeller had yet reached its present state of perfection, it is stated as then highly probable that fine sailing vessels, fitted with auxiliary screw-power, would be found able, if not to rival, at least to approach, full-powered and expansively acting steam-ships, in respect of their capability of making a long voyage with certainty and in a reasonably short time.

"Another application of the screw, although inferior in general importance to its application as a propeller to ordinary ships," says the same report, "is certainly deserving of more attention than is commonly paid to it, namely, as a manœuvrer to those large ships in which engines of considerable power cannot be placed, or in which it is considered unadvisable to place them. No doubt can be entertained of the efficiency of such an instrument worked by an engine of even fifty horse-power. The full extent, however, of its utility cannot perhaps be thoroughly appreciated until it shall have been extensively used in her Majesty's navy."

Since the date of this report that experience which was wanted has been obtained, and the extensive use of the screw has been adopted, and the results fully confirm all those anticipations.

77. But it is not only in her Majesty's navy, but in the national commercial marine, and not only as an auxiliary propeller, but as an independent and most efficient agent of propulsion, that the screw has been found to answer in practical navigation. In 1849,

* Bourne "on the Screw-propeller," Chap. IV.

before it had yet attained all its present degree of perfection, it was in extensive operation under the direction of the General Screw Shipping Company. Seven vessels belonging to that company were in operation during the twelve months ending 31st December, 1849, during which time they performed 170 voyages, being an average of about 24½ voyages per vessel. The total distance run was 110849 geographical miles, being at the average rate of 15835 miles per vessel, and about 648 miles per voyage. The average speed was 8 to 8½ geographical miles per hour, and only one casualty, and that one in the Thames, occurred during the year.

The speed of the best and most recent of these vessels in still water, running the measured mile in the long reach of the Thames, was found to be 9·68 knots per hour.

78. Practical authorities have suggested, that the greatly increased and rapidly increasing number of screw ships running between the British and American ports, suggests the expediency of a revision of the post-office contracts, with a view to public economy, without any real sacrifice of efficiency. It is considered that no difference of time worthy of consideration now prevails between the passages of the mail-packets and the screw-vessels; but even admitting a difference, it is certainly not so great as that which exists between the speed of the mail and that of the express trains on railways. If then the mail contracts on the iron lines are sufficiently well performed by the trains of second-rate speed, why may not the like contracts on the lines of water be similarly executed, where the difference of cost would be enormous, and the difference of speed comparatively insignificant.

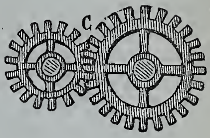
It is obvious that these observations are applicable not only to the lines of steamers which carry the United States and Canadian, but also to the West Indian, and in a word, to all the ocean lines.

79. But when screw propulsion is used, a much greater velocity of revolution is required to be given to the screw-shaft,—a much greater number of revolutions per minute being necessary, than the greatest number of strokes per minute made by any steam-engine of the common construction. It was necessary, therefore, in adopting screw propulsion, either to provide expedients by which the velocity of rotation of the screw-shaft shall be greater than that of the crank-shaft, in the requisite proportion, or to modify the form and proportions of the steam cylinders and their appendages, so that the number of strokes per minute should be augmented, so as to be equal to the necessary number of revolutions per minute of the screw-shaft.

Both these contrivances have been adopted by different constructors. Engines constructed on the former plan are called *geared engines*, and those constructed on the latter *direct acting engines.*

80. In geared engines the cranks are formed on one shaft, and the screw fixed upon another, the directions of the two shafts being parallel. On the crank-shaft is fixed a toothed-wheel, which works in a smaller one, called a pinion, fixed on the screw-shaft. Thus in fig. 24, A may be regarded as the pinion fixed on the screw-shaft, and B the wheel fixed on the crank-shaft, the teeth of the one being engaged in those of the other at C.

Fig. 24.



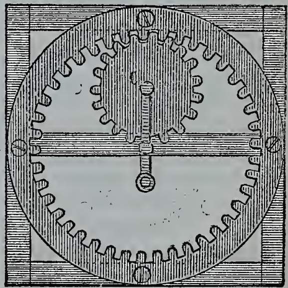
It is evident that the velocity of rotation of A will be greater than that of C in the same proportion as that in which the number of teeth in C is greater than the number of teeth in A. It is always possible, therefore, with a given speed of the crank-shaft, to impart a speed greater in any required proportion to the screw-shaft by regulating in a corresponding manner the proportion of the teeth in those geared wheels.

81. One of the objections to the use of gearing in sea-going vessels is the liability of the teeth to rapid wear, and to fracture from sudden shocks in a rough sea. In order to diminish the risk of this by distributing the pressure over a greater number of teeth, Mr. Fairbairn has adopted in large screw-engines, constructed by him for the Royal Navy, a system of internal gearing in which the crank-shaft wheel has the teeth on its internal periphery, the screw-shaft pinion revolving within it, as shown in fig. 25.

In screw-vessels of war, all the machinery should be placed below the water-line, so as to be as effectually protected from shot as the screw itself is.

82. When direct-acting engines without gearing are applied to screw-propelled vessels, the reciprocating motion of the piston must be equal to the velocity of the screw, that is, the number of strokes per minute of the piston must be equal to the number of revolutions per minute of the screw. Now to render this compatible with a sufficiently moderate rectilinear motion of the piston, the length of the stroke must bear a very small proportion to the diameter of the cylinder. This has, in many cases, rendered it necessary in such vessels to subdivide the power of the engines among four smaller cylinders, all the pistons being directly attached to cranks on the screw-shaft instead of producing it by two larger cylinders, in which an unmanageable proportion must be adopted between the diameter and the stroke.

Fig. 25.



Another advantage derived from this subdivision of power is, that a number of small cylinders, ranged often in a horizontal position on either side of the screw-shaft, allow of the play of all the reciprocating parts within a small height, so as to keep the whole below the water-line.

83. Another expedient for the protection of the machinery from shot, is to place the coal-boxes on each side of it, and between it and the timbers of the vessel, so that before a shot could reach it, the fuel must be thoroughly penetrated.

84. The efficiency of a marine, like that of a land engine, depends on the exact regulation of the slides by which the admission and escape of the steam to and from the cylinder is governed. In all cases the steam should be admitted at either end of the cylinder a little before the arrival of the piston there, and at the same moment the escape to the condenser should be stopped. By this means the piston, on arriving at the end of the stroke, is received by the steam just admitted mixed with a small portion of uncondensed steam and air, whose escape to the condenser has been intercepted. These form a sort of air-cushion, against which the stroke of the piston is broken, an effect which is called by the practical men, not inappropriately; *cushioning* the piston. When the steam is worked expansively, the slides must be capable of such regulation as to shut it off at any required fraction of the entire stroke, and when not so worked, it ought at all events to be shut off before the stroke is quite completed, so as to relieve the piston from its action a little before the termination of the stroke.

It is easy to conceive that, to accomplish all these points, the slides require the nicest imaginable adjustment; and the openings for the admission and escape of steam, the most exact regulation both as to magnitude and position.

85. It will be evident on comparing the pitch of the ordinary screw with the progressive rate at which the vessel moves through the water, that, to produce the necessary speed, a much greater velocity of rotation must be imparted to the screw, than is consistent with the ordinary rate at which steam-engines work. It has been already shown that this great velocity of rotation has been obtained either by the interposition of gearing so adapted as to augment the velocity, or by assimilating the engine in its form and structure to a locomotive.

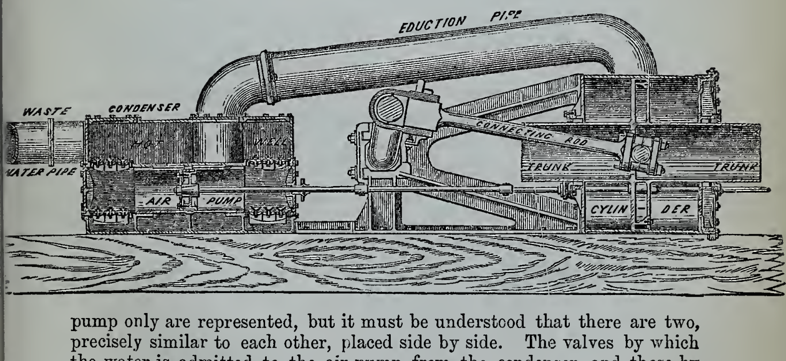
86. An example of a marine-engine, by which the necessary velocity is imparted to the screw-shaft, by means of intermediate gearing, is presented in the case of the screw-engine constructed by Messrs. Penn and Son, for the "Great Britain" steam-ship. The engines which are represented in fig. 26, are constructed on the oscillating principle, and are almost identical with the paddle-wheel engines, built by the same firm for the "Sphinx."

The "Great Britain" is a vessel of 3500 measured tons; her tonnage by deplacement being 2970, and her draught 16 feet. The diameter of the cylinder is $82\frac{1}{2}$ inches; the length of stroke, 6 feet; the nominal power, 500 horses; the diameter of the screw, $15\frac{1}{2}$ feet; its pitch, 19 feet, and its length, 3 feet 2 inches. The screw has three arms or blades, and its shaft is connected with the crank-shaft by a pair of toothed-wheels, which have a multiplying power of 3 to 1, so that for every stroke of the piston, the screw-shaft revolves three times. The ample proportion of $17\frac{1}{2}$ square feet of heating surface per nominal horse-power, is provided in the boiler.

The crank-shaft, being put in motion by the engine, carries round the great cog-wheel, or combination of cog-wheels, which are fixed upon it; and this wheel acting on smaller ones called pinions, on the screw-shaft, impart to the latter the threefold velocity of revolution just mentioned.

87. As an example of screw-propelling engines working without gearing, we give in fig. 27 those constructed by Messrs. Penn and Son for H. M.'s screw-steamers "Arrogant" and "Encounter." In this case the cylinders are horizontal, and are traversed through the centre by a pipe or trunk, upon which the piston is cast. This trunk is projected through both ends of the cylinder—the orifices through which it passes being rendered steam-tight by proper packing. One end of the connecting-rod is attached to the centre of the trunk, the other end being connected with the crank, which is formed directly upon the screw-shaft. The air-pump lies in a horizontal position, is double-acting, and placed within the condenser. A large pipe, called the eduction pipe, leads from the cylinder to the condenser, where the condensation is produced by a jet of cold water, and the warm water resulting from the process is ejected by the air-pump through the waste-pipe, and discharged overboard. In fig. 27 one cylinder and one air-

Fig. 27.



pump only are represented, but it must be understood that there are two, precisely similar to each other, placed side by side. The valves by which the water is admitted to the air-pump from the condenser, and those by which it passes from the air-pump to the hot well and waste-pipe, consist of several discs of caoutchouc kept down by a central bolt, so as to cover radial slits or orifices in a perforated plate. These valves are found to operate without noise or shock, notwithstanding the high speed at which the engine must work, in order to give the necessary velocity to the screw-shaft without intervening gearing. The diameter of the cylinder of the "Arrogant" and "Encounter" is 60 inches, and the diameter of the trunk 24 inches; the latter being deducted from the former, leaves an effective piston area equal to that of a piston 55 inches in diameter. In the "Arrogant" the length of stroke is 3 feet, and in the "Encounter" it is 2 feet 3 inches. The nominal power of both engines is 360 horses ; and the diameter of the "Arrogant's" screw is 15 feet 6 inches, that of the "Encounter" being 12 feet. The pitch of both is 15 feet, and the length 2 feet 6 inches. The "Arrogant" is a vessel of 1872 tons burden, and the "Encounter" of 953 tons. The whole machinery, including the boilers, is placed below the water line, so as to be protected from shot.*

88. The forms of screw-propelling engines, whether they act on the screw-shaft by intermediate gearing or directly, are infinitely various. Drawings of not less than 15 different forms of geared-engines, and the like number of direct acting engines, are given in two large plates prefixed to Mr. Bourne's work on the screw-propeller, to which we must refer those who require information of this detailed description. In the vessels of the Royal Marine generally the cylinders are placed upon the sides, so that, by diminishing the total height of the machinery above the floor on which it rests, it may be kept below the water-line. In commercial vessels a form of engines is frequently employed resembling the land beam-engines, with the cylinder at one end of the beam, and the connecting-rod at the other. In such cases the connecting-rod extends downwards from the end of the beam to the crank. In either case the cylinder is inverted, and the connecting-rod proceeds from the end of the piston-rod to turn the crank, the end of the piston-rod being of course steadied by suitable guides. According to Mr. Bourne, the construction of the engines described above in the case of the "Arrogant" and "Encounter" is, on the whole, the best for screw-vessels, but he thinks it might be preferable to put the trunk into the air-pump instead of the cylinder. He considers also that the condenser might be dispensed with, and the condensations performed in the air-pump. In that case the flow of water to and from the air-pump might be governed by a slide-valve, similar to that which is employed to regulate the admission and escape of steam to and from the cylinder. It seems probable that slide-valves may be brought into general use for pumps of every sort, but in the case of ordinary ones for raising water these valves need not be like the common slide-valves, which in fact are not well adapted to give sufficient area for such purposes, but may consist of a short wide cylinder with gridiron orifices revolving slowly at the top and bottom of the air air-pump.

89. The general arrangement of the machinery and fuel in screw-propelled vessels of the Royal Navy is illustrated by the transverse section of H.M.'s screw steam-packet "Plumper," shown in fig. 28.

* Figs. 26 and 27 are copied, with the permission of the publisher and the author, from Brande's "Dictionary of Science and Art," to which the

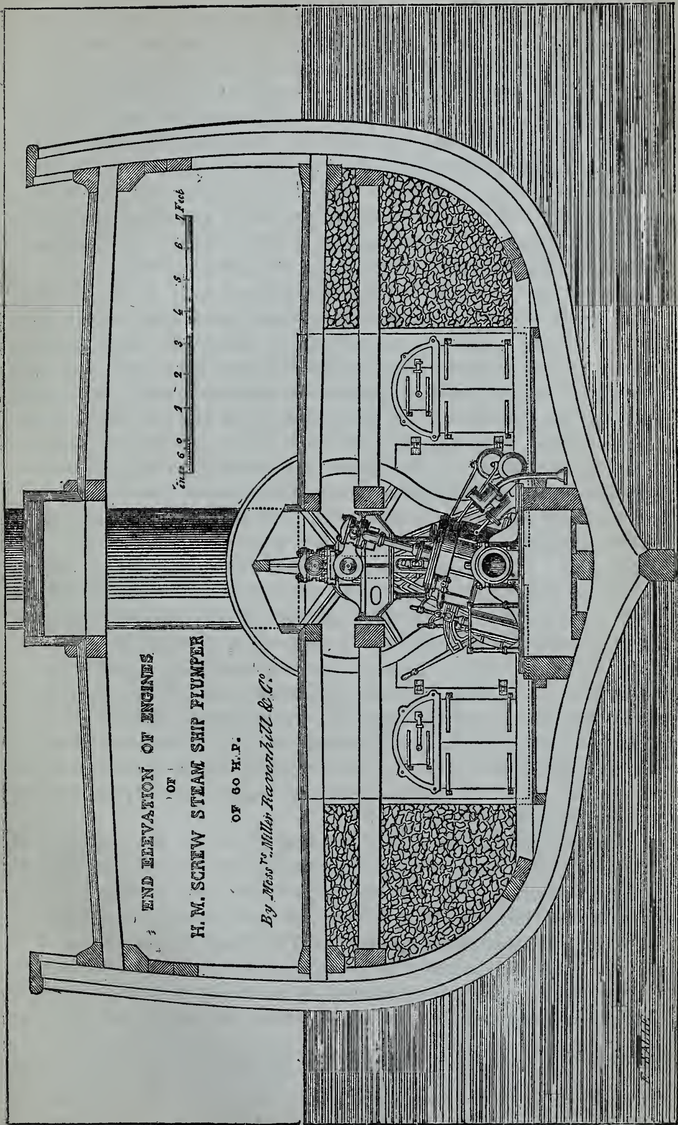

END ELEVATION OF ENGINES
OF
H. M. SCREW STEAM SHIP PLUMPER
OF 60 H.P.
By Mess^rs. Miller Ravenhill & C^o.
Ins 6 0 1 2 3 4 5 6 7 Feet

Fig. 28.

90. The question of auxiliary steam power to be used occasionally, as well for commercial as for war purposes, is one of the highest importance and interest, and one, moreover, which experience has not yet enabled us perfectly to understand and elucidate. For commercial purposes the saving of fuel, when the vessel has favourable winds, and the adaptation of her structure to the conditions necessary for a sailing-vessel, is of the highest importance; and in naval warfare a propelling power, however inadequate it may be for constant propulsion and the maintenance of high speeds in long voyages, may nevertheless be all-sufficient for conducting vessels into action or into hostile ports.

91. It has been already stated on the authority of Mr. Bourne, and as the result of experiments made on a large scale, that screw-vessels intended to go head to wind and work against head-seas, are not as efficient with the same consumption of fuel as paddle-wheel vessels. Under the combined operation of sails and steam, however, they are generally as efficient, and, when deeply laden, more so. A screw-vessel being divested of paddle-boxes partakes more of the character of a sailing-ship; nevertheless, from the experiments made with the "Niger" and "Basilisk," it does not appear that a screw-vessel is more efficient under sails than a paddle-vessel, though such a result may naturally be expected. The advantages, therefore, which attend the use of screw-propelling engines as an auxiliary power, do not result from any superiority of the screw as a propeller, nor from the increased facility which it presents for the application of sails, but are to be ascribed to the late employment in screw-vessels of wind-power which costs nothing, instead of steam-power which costs much, and also to the maintenance of lower rates of speed than are thought necessary in paddle-wheel vessels. The screw is a less cumbrous propeller than the paddle, and since it permits a much higher speed of the engine, a greater engine power may be compressed in a smaller compass.

On the whole, therefore, the screw for all the purposes of auxiliary propulsion is much to be preferred; nevertheless it must be understood that its superior eligibility is not so much due to its greater efficiency, as to the greater convenience in the application of auxiliary steam-power which its employment affords.

92. The horse-power of marine engines is either nominal or real. The nominal power is estimated by assuming a certain average effective pressure of steam, and a certain average linear velocity

reader is referred for a great mass of important details, for which we cannot here afford space. Still further information on the same subject may be found in Mr. Bourne's work "on the Screw-propeller" already quoted, that gentleman being also the author of the article in Brande.

of the piston. The pressure multiplied by the velocity gives the effective force of the piston, or, what is the same, of the engine exerted through a given number of feet per minute; and since the force called a horse-power means 33000 lbs. acting thus one foot per minute, it follows that the nominal power of the engine will be found by dividing the effective force exerted by the piston, multiplied by the number of feet per minute through which it acts, by 33000.

It is assumed in all Admiralty contracts, and generally also in those of the commercial marine, that, after deducting from the total pressure of steam in the boiler that portion which is neutralised by the gases and uncondensed steam in the condenser, the friction of the moving parts and all other sources of resistance, the actual available or effective pressure of steam upon the piston is at the rate of 7 lbs. per square inch of piston surface. The total nominal effective action of the piston in pounds will therefore be found by multiplying the number of square inches in the area of the piston by 7.

93. In the following tables, obtained from the government authorities, will be found a complete statement of the strength of her Majesty's steam navy up to the 1st of April, 1856.

By Table I. it appears that the number of line-of-battle ships fitted and fitting with the screw-propeller was then 43, carrying a total number of 3797 guns, and propelled by engines of the collective power of 22950 horses. This is at the average rate of 88⅓ guns, and 533 horses per vessel; the proportion of guns to horses being about 6 horses per gun.

By Table II. it appears that the number of frigates and mortar-ships was 24, carrying collectively 889 guns, and propelled by engines of 10560 horse-power, being at the average rate of 37 guns, and 440 horses per vessel; the proportion of horses to guns being about 12 horses per gun.

By Table III. it appears that there were 90 war steamers fitted with paddle-wheels, carrying the total number of 500 guns, and propelled by engines having the collective power of 24640 horses, being at the average rate of 5½ guns, and 274 horses per vessel; the proportion of horse-power to guns being about 50 horses per gun.

By Table IV. it appears that there were 76 smaller vessels fitted with screw-propellers, consisting of corvettes, sloops, and despatch boats, carrying in all 761 guns, and propelled by engines of the collective power of 16202 horses, being at the average rate of 10 guns and 213 horses per vessel; the proportion of horse-power to guns being therefore about 21 horses per gun.

In Table V. is given the number and power of the troop and store-ships, water-tanks, &c.; in Table VI. a statement of the steam-propelled gun-boats ; and in Table VII. a general summary of the entire steam navy.

In Table VIII. is given a statement of the commercial steam navy in March 1853.

TABLE I.

Line-of-Battle Ships fitted and fitting with the Screw-Propeller in Her Majesty's Navy.

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
					Brought forward	1253	7500		Brought forward	2475	14700
1	Agamemnon . .	91	600	16	Exmouth . .	90	400	30	Orion . . .	91	600
2	Ajax . . .	60	450	17	Gibraltar . .	100	800	31	Pembroke . .	60	200
3	Algiers . . .	90	450	18	Hannibal . .	90	450	32	Princess Royal .	91	400
4	Blenheim . .	60	450	19	Hastings . .	60	200	33	Renown . .	90	800
5	Brunswick . .	80	400	20	Hawke . . .	60	200	34	Revenge . .	90	800
6	Cæsar . . .	91	400	21	Hero . . .	90	600	35	Royal Albert. .	121	500
7	Centurion . .	80	400	22	Hogue . . .	60	450	36	Royal George .	102	400
8	Colossus . .	80	400	23	Howe . .	120	1000	37	Royal Sovereign	120	1000
9	Conqueror . .	100	800	24	Irresistible . .	80	400	38	Russell . . .	60	200
10	Cornwallis . .	60	200	25	James Watt .	91	600	39	St. Jean d'Acre .	101	600
11	Cressy . . .	80	400	26	Majestic . .	80	400	40	Sanspareil . .	70	350
12	Donegal . .	100	800	27	Marlborough .	130	800	41	Victor Emanuel.	90	600
13	D. of Wellington	131	700	28	Mars . . .	80	400	42	Victoria . .	120	1000
14	Edgar . . .	90	600	29	Nile . . .	91	500	43	Windsor Castle .	116	800
15	Edinburgh . .	60	450								
		1253	7500			2475	14700		Total . .	3797	22950

TABLE II.

Frigates and Mortar-ships fitted and fitting with the Screw-Propeller in Her Majesty's Navy.

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Amphion .	34	300		Bt. forward	355	4140		Bt. forward	621	7350
2	Ariadne . .	30	350	10	Doris . .	32	800	18	Liffey . . .	50	600
3	Arrogant .	46	360	11	Emerald . .	50	600	19	San Fiorenzo .	50	600
4	Aurora . .	50	400	12	Eurotas . .	12	200	20	Sea-horse . .	12	200
5	Bacchante . .	50	600	13	Euryalus . .	51	400	21	Shannon .	51	600
6	Chesapeake .	50	400	14	Forte . .	50	400	22	Termagant .	24	310
7	Curaçoa . .	30	350	15	Forth . .	12	200	23	Topaz . .	50	600
8	Dauntless .	33	580	16	Horatio . .	8	250	24	Tribune . .	31	300
9	Diadem . .	32	800	17	Impérieuse .	51	360		Total . .	889	10560
		355	4140			621	7350				

TABLE III.—*A List of War Steamers in Her Majesty's Service fitted with Paddle-wheels.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Alecto	5	200		Bt. forward	112	7560		Bt. forward	283	15869
2	Albany	4	100	32	Furious	16	400	62	Penelope	16	650
3	Ardent	5	200	33	Fury	..	515	63	Porcupine	3	132
4	Antelope	3	260	34	Geyser	6	280	64	Prometheus	5	200
5	Argus	6	300	35	Gorgon	6	320	65	Rhadamanthus	4	220
6	Asp	..	50	36	Gladiator	6	430	66	Redpole	1	160
7	Avon	3	160	37	Harpy	1	200	67	Retribution	28	400
8	Bann	..	80	38	Hecate	6	240	68	Rosamond	6	280
9	Banshee	2	350	39	Hecla	6	240	69	Sampson	6	467
10	Barracouta	6	300	40	Hermes	6	220	70	Salamander	6	220
11	Basilisk	6	400	41	Hydra	6	220	71	Scourge	6	420
12	Black Eagle	..	260	42	Inflexible	6	378	72	Shearwater	8	160
13	Blood Hound	3	150	43	Jackal	4	150	73	Sidon	22	560
14	Brune	..	80	44	Kite	3	170	74	Spiteful	6	280
15	Bull Dog	6	500	45	Leopard	18	560	75	Spitfire	5	140
16	Buzzard	6	300	46	Lightning	3	100	76	Sphinx	6	500
17	Caradoc	2	350	47	Lizard	1	150	77	Stromboli	6	280
18	Centaur	6	540	48	Locust	3	100	78	Styx	6	280
19	Columbia	6	100	49	Lucifer	2	180	79	Tartarus	4	136
20	Comet	..	80	50	Magicienne	16	400	80	Terrible	21	800
21	Cuckoo	3	100	51	Medea	6	350	81	Trident	6	350
22	Cyclops	6	320	52	Medina	4	312	82	Triton	3	260
23	Dasher	2	100	53	Medusa	4	312	83	Valorous	16	400
24	Dee	4	200	54	Merlin	6	312	84	Vesuvius	6	280
25	Devastation	6	400	55	Oberon	3	260	85	Virago	6	300
26	Dragon	6	560	56	Odin	16	560	86	Vulture	6	470
27	Dover	..	90	57	Osborne	2	430	87	Weser	6	160
28	Driver	6	280	58	Otter	3	120	88	Widgeon	..	90
29	Firefly	4	220	59	Pigmy	3	100	89	Wildfire	..	76
30	Firebrand	6	410	60	Polyphemus	5	200	90	Zephyr	3	100
31	Fire Queen	..	120	61	Pluto	4	100				
		112	7560			283	15869		Total	500	24640

TABLE IV.—*Corvettes, Sloops, and Despatch Gun-vessels fitted and fitting with the Screw-Propeller in Her Majesty's Service.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Alacrity		200		Bt. forward	305	5700		Bt. forward	541	1090
2	Alert	16	100	27	Flying Fish	6	350	52	Plumper	9	600
3	Ariel	9	60	28	Fox Hound	4	200	53	Pylades	20	350
4	Archer	14	202	29	Harrier	17	100	54	Rattler	11	200
5	Arrow	4	160	30	Hesperus	..	120	55	Recruit	6	160
6	Assurance	4	200	31	Highflyers	21	250	56	Renard	4	200
7	Beagle	4	160	32	Hornet	17	100	57	Rifleman	8	100
8	Brisk	14	250	33	Icarus	..	..	58	Ringdove	4	200
9	Cadmus	20	400	34	Intrepid	6	350	59	Roebuck	6	350
10	Cameleon	16	100	35	Lapwing	4	200	60	Reward	4	200
11	Challenger	20	400	36	Lynx	4	160	61	Satellite	20	400
12	Charybdis	20	400	37	Lyra	8	60	62	Scout	20	400
13	Clio	20	400	38	Malacca	17	200	63	Scylla	20	400
14	Conflict	8	400	39	Minx	3	10	64	Sharpshooter	8	202
15	Coquette	4	200	40	Miranda	14	250	65	Snake	4	160
16	Cordelia	8	60	41	Mohawk	4	200	66	Sparrowhawk	4	200
17	Cormorant	4	200	42	Mutine	16	100	67	Surprise	4	200
18	Cossack	20	250	43	Myrmidon	3	150	68	Swallow	9	60
19	Cruiser	17	60	44	Niger	14	400	69	Tartar	20	250
20	Curlew	9	60	45	Nimrod	6	350	70	Teazer	3	40
21	Desperate	8	400	46	Osprey	4	200	71	Victor	6	350
22	Encounter	14	360	47	Pearl	20	400	72	Vigilant	4	200
23	Esk	21	250	48	Pelican	16	100	73	Viper	4	160
24	Etna	14	200	49	Pelorus	20	400	74	Wanderer	4	200
25	Falcon	17	100	50	Phœnix	6	200	75	Wasp	14	100
26	Fawn	..	128	51	Pioneer	6	350	76	Wrangler	4	160
		305	5700			541	10900		Total	761	16202

TABLE V.—*Trooper, Store-ships, Water-tanks, Flour-mills, Yachts, and Floating-factories.*

	Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.		Name.	Guns.	Horse Power.
1	Abundance	..	100		Bt. forward		1856		Bt. forward	11	4076
2	Assistance	..	400	18	Hearty	..	100	34	Prospero	..	144
3	Advice	..	100	19	Helen Faucit	..	..	35	Resistance	10	400
4	Adder	..	100	20	Himalaya	..	700	36	Resolute	..	400
5	African	..	90	21	Humber	..	30	37	Simoom	8	350
6	Bruiser	..	100	22	Industry	2	80	38	Sprightly	..	100
7	Buffalo	..	60	23	Malta	..	50	39	Supply	2	80
8	Bustler	..	100	24	Megæra	6	350	40	Sulina	..	120
9	Chasseur	..	100	25	Monkey	..	130	41	Sultana	..	..
10	Confiance	..	100	26	Moslem	..	120	42	Thais	..	80
11	Coromandel	..	..	27	Myrtle	..	50	43	Torch	..	150
12	Crescent	..	50	28	Nimble	..	..	44	Transit	..	500
13	Danube	..	..	29	Pera	..	30	45	Urgent	..	450
14	Echo	..	140	30	Perseverance	2	360	46	Vulcan	6	350
15	Elfin	..	140	31	Pike	..	50	47	Wye	..	100
16	Fearless	..	76	32	Pigeon	..	50				
17	Fox	..	200	33	Princess Alice	1	120		Total	37	7300
			1856			11	4076				

TABLE VI.

Statement of the Total Number and Power of Steam Gun-boats in the Royal Navy on the 1st *April*, 1856.

No.	Guns.	Horse Power.	Total Guns.	Total Horse Power.
122	4	60	488	7320
13	4	40	52	520
20	2	20	40	400
155	10	120	580	8240

TABLE VII.

Statement of the Number and Power of Steam Vessels of all classes in the Royal Navy on the 1st *April*, 1856.

	No.	Guns.	Horse Power.
Line-of-Battle Ships	43	3797	22950
Frigates & Mortar-ships.	24	889	10560
Paddle-wheel Vessels	90	500	24640
Corvettes, Sloops, &c.	76	761	16202
Troop-ships	47	37	7300
Gun-boats	155	580	8240
	435	6564	89892

TABLE VIII.—*Showing the number of vessels (wood and iron) belonging to the Mail Contract Steam Packet Companies in March*, 1853; *also their Tonnage and Horse Power, from Parliamentary return ordered to be printed* 2[illegible]*th June*, 1853.

To what Company belonging.	Number of Vessels.			Tonnage.			Horse Power.		
	Wood.	Iron.	Total.	Wood.	Iron.	Total.	Wood.	Iron.	Total.
Peninsula and Oriental	11	22	33	11800	26449	38249	4086	7481	11567
Royal West India	19	1	20	32612	2700	35312	8750	800	9550
British and N. American	8	1	9	14991	2500	17491	5690	1000	6690
Pacific	..	8	8	..	6688	6688	..	2298	2298
General Screw Steam Shipping	..	8	8	..	13496	13496	..	2250	2250
Australian	..	5	5	..	8600	8600	..	1800	1800
South Western	..	4	4	..	1612	1612	..	677	677
African	..	4	4	..	3920	3920	..	530	530
Total	38	53		59403	65965		18526	16836	
	Grand total		91	Grand total		125368	Grand total		35362

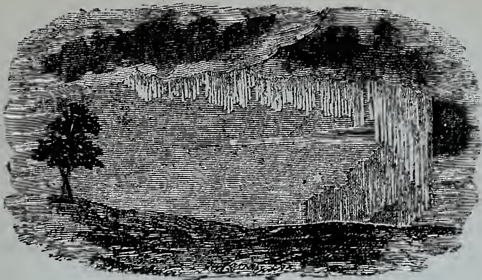


Fig. 4.

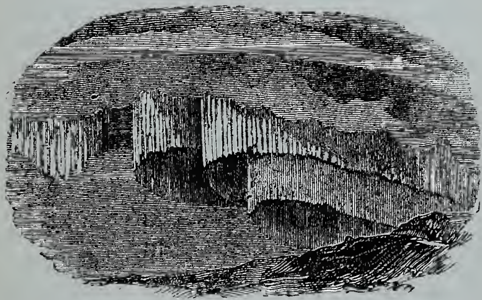


Fig. 5.

THUNDER AND LIGHTNING, AND THE AURORA BOREALIS.

1. Atmospheric Electricity.—2. The air generally charged with positive electricity.—3. Subject to variations and exceptions.—4. Diurnal variations of electrical intensity. Observations of Quetelet. — 5. Irregular and local variations and exceptions. — 6. Variations dependent on the season and weather.—7. Methods of observing atmospheric electricity.—8. Methods of ascertaining the electrical condition of the higher strata.—9. Remarkable experiments of Romas, 1757.—10. Electrical charge of clouds varies.—11. Thunder and lightning.—12. Form and extent of the flash of lightning.—13. Cause of the rolling of thunder.—14. Affected by the zigzag form of lightning.—15. Affected by the varying distance of different parts of the flash.—16. Affected by echo and by interference.—17. Inductive action of clouds on the earth.—18. Formation of Fulgurites explained. —19. Accidents of the surface which attract lightning.—20. Lightning follows conductors by preference—its effects on buildings.—21. Con-

ductors or paratonnerres for the protection of buildings.—22. Effects of lightning on bodies which it strikes.—23. The Aurora Borealis — the phenomena unexplained. — 24. General character of the meteor.—25. Description of auroras seen in the polar regions by M. Lottin.

1. There is no part of physical science in which the researches of modern investigators have been attended with such signal success, as those which have been directed to the discovery of the influence of electricity upon the atmosphere. Indeed it would be difficult to name any atmospheric change, which is not directly or indirectly connected with electric agency. It is true that these atmospheric phenomena, fugitive and transitory as most of them are, have not been in all cases traced with clearness and certainty to their causes, that the relation of some of them to the agency of electricity is rendered probable, more from general appearances than by distinct and satisfactory demonstration, and that some of them, which are evidently of electric origin, have, nevertheless, remained unexplained by, or not reduced to, any of the known laws which govern that physical agent. Still there is much that falls under the general principles of electric science, and those phenomena which remain with or without any satisfactory explanation require to be stated, that those who pursue this part of physical science, with a view to extend its limits, may be guided to proper subjects of observation and investigation.

How important the topics embraced under the general head of atmospheric electricity are, will be understood when it is stated, that upon the electric condition of the atmosphere, and the changes incidental to it, depend not only the stupendous phenomena of thunder-storms, but also the whole of that beautiful and interesting class of phenomena comprised under the general name of Aurora Borealis.

2. The terrestrial globe which we inhabit is invested with an ocean of air, the depth of which is about the 200th part of its diameter. It may, therefore, be conceived by imagining a coating of air, the tenth of an inch thick, investing a twenty-inch globe. This aerial ocean, relatively shallow as it is, at the bottom of which the tribes of organised nature have their dwelling, is, nevertheless, the theatre of stupendous electrical phenomena.

It may be stated as a general fact, that the atmosphere which thus covers the globe is charged with positive electricity, which, acting by induction on the superficial stratum of the globe on which it rests, decomposes the natural electricity, attracting the negative fluid to the surface and repelling the positive fluid to the inferior strata. The globe and its atmosphere may therefore be not inaptly compared to a Leyden phial, the outer coating of which being placed in connection with the prime conductor of a machine, is charged with positive electricity, and the inner coating being in connection with the ground, is charged by induction with negative electricity. The outer coating represents the atmosphere, and the inner the superficial stratum of the globe.

3. This normal state of the general atmospheric ocean is subject to variations and exceptions, variations of intensity and exceptions in quality or name. The variations are periodical and accidental. The exceptions local, patches of the general atmosphere in which clouds float being occasionally charged with negative electricity.

4. The intensity of the electricity with which the atmosphere is charged, varies, in the course of twenty-four hours, alternately increasing and decreasing. M. Quetelet found that the first maximum was manifested about 8 A.M., and the second about 9 P.M. The minimum in the day was at 3 P.M. He found also that the mean intensity was greatest in January and least in June.

5. Such are the normal changes which the electrical condition of the air undergoes when the atmosphere is clear and unclouded. When, however, the firmament is covered with clouds, the electricity is subject during the day to frequent and irregular changes not only in intensity but in name; the electricity being often negative, owing to the presence of clouds over the place of observation, charged, some with positive, and some with negative electricity.

6. The intensity of the electricity of the air is also affected by the season of the year, and by the prevalent character and direction of the winds; it varies also with the elevation of the strata, being in general greater in the higher than in the lower regions of the atmosphere. The intensity is generally greater in winter, and especially in frosty weather, than in summer, and when the air is calm than when winds prevail.

Atmospheric deposits, such as rain, hail, snow, &c., are sometimes positive and sometimes negative, varying with the direction of the wind. North winds give positive, and south winds negative deposits.

7. The electricity of the atmosphere is observed by erecting in it, to any desired elevation, pointed metallic conductors, from the lower extremities of which wires are carried to electroscopes of various forms, according to the intensity of the electricity to be observed. So immediate is the increase of electrical tension in rising through the strata of the air, that a gold leaf electroscope,

properly adapted to the purpose, and reduced to its natural state when placed horizontally on the ground, will show a sensible divergence when raised to the level of the eyes.

8. To ascertain the electrical condition of strata too elevated to be reached by a fixed conductor, the extremity of a flexible wire, to which a metallic point is attached, is connected with a heavy ball, which is projected into the air by a gun or pistol, or to an arrow projected by a bow. The projectile, when it attains the limit of its flight, detaches the wire from the electroscope, which then indicates the electrical state of the air at the highest point attained by the projectile.

9. The vast quantities of electricity with which the clouds are sometimes charged, were rendered manifest in a striking manner by the well-known experiments made by means of kites by Romas in 1757. The kite, carrying a metallic point, was elevated to the strata in which the electric cloud floated. A wire was connected with the cord, and carried from the pointed conductor borne by the kite to a part of the cord at some distance from the lower extremity, where it was turned aside and brought into connection with an electroscope, or other experimental means of testing the quantity and quality of the electricity with which it was charged. Romas drew from the extremity of this conducting wire not only strong electric sparks, but blades of fire nine or ten feet in length, and an inch in thickness, the discharge of which was attended with a report as loud as that of a pistol. In less time than an hour, not less than thirty flashes of this magnitude and intensity were often drawn from the conductor, besides many of six or seven feet and of less length.

10. It has been shown by means of kites thus applied, that the clouds are charged some with positive and some with negative electricity, while some are observed to be in their natural state. These circumstances serve to explain some phenomena observed in the motions of the clouds which are manifested in stormy weather. Clouds which are similarly electrified repel, and those which are oppositely electrified attract each other. Hence arise motions among such clouds of the most opposite and complicated kind. While they are thus reciprocally attracted and repelled in virtue of the electricity with which they are charged, they are also transported in various directions by the currents which prevail in the atmospheric strata in which they float, these currents often having themselves different directions.

11. Such appearances are the sure prognostics of a thunderstorm. Clouds charged with contrary electricities affect each other by induction, and mutually attract, whether they float in the same stratum or in strata at different elevations. When they

come within *striking distance*, the contrary fluids rush to each other, and an electrical discharge takes place.

The clouds, however, unlike the metallic coatings of the jar, are very imperfect conductors, and consequently, when discharged at one part of their vast extent, they preserve elsewhere their electricity in its original intensity. Thus, the first discharge, instead of establishing equilibrium, rather disturbs it, for the part of the cloud which is still charged is alone attracted by the part of the other cloud in which the fluid has not yet been neutralised. Hence arise various and complicated motions and variations of form of the clouds, and a succession of discharges between the same clouds must take place before the electrical equilibrium is established. This is necessarily attended by a corresponding succession of flashes of lightning and claps of thunder.

12. The form of the flash in the case of lightning, like that of the spark taken from an electrified conductor, is zigzag. The doublings or acute angles formed at the successive points when the flash changes its direction vary in number and proximity. The cause of this zigzag course, whether of the electric spark or of lightning, has not been explained in any clear or satisfactory manner.

The length of the flashes of lightning also varies; in some cases they have been ascertained to extend to from two-and-a-half to three miles. It is probable, if not certain, that the line of light exhibited by flashes of forked lightning are not in reality one continued line simultaneously luminous, but that on the contrary the light is developed successively as the electricity proceeds in its course, the appearance of a continuous line of light being an optical effect, analogous to the continuous line of light exhibited when a lighted stick is moved rapidly in a circle, the same explanation being applicable to the case of lightning.

13. As the sound of thunder is produced by the passage of the electric fluid through the air which it suddenly compresses, it is evolved progressively along the entire space along which the lightning moves. But since sound moves only at the rate of 1100 feet per second, while the transmission of light is so rapid that in this case it may be considered as practically instantaneous, the sound will not reach the ear for an interval greater or less after the perception of the light, just as the flash of a gun is seen before the report is heard.

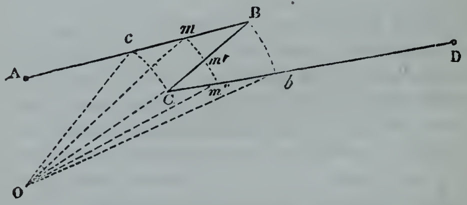
By noting the interval, therefore, which elapses between the perception of the flash and that of the sound, the distance of the point where the discharge takes place can be computed approximately, by allowing 1100 feet for every second in the interval.

But since a separate sound is produced at every point through which the flash passes, and as these points are at distances from the observer which vary according to the position, length, direction, and form of the flash, it will follow necessarily that the sounds produced by the same flash, though practically simultaneous, because of the great velocity with which the electricity moves, arrive at the ear in comparatively slow succession.

The varying loudness of the successive sounds heard in the rolling of thunder, proceeds in part from the same causes as the varying intensity of the light of the flash. But it may, perhaps, be more satisfactorily explained by the combination of the successive discharges of the same cloud, rapidly succeeding each other, and combining their effects with those arising from the varying distances of different parts of the same flash.

14. It appears to us that the varying intensity of the rolling of thunder may also be very clearly and satisfactorily explained by the zigzag form of the flash, combined with the effect of the varying distance; and it seems extraordinary that an explanation so obvious has not been suggested. Let A, B, C, D (fig. 1), be a

Fig. 1.



part of a zigzag flash seen by an observer at O. Taking O as a centre, suppose arcs C c and B b of circles to be drawn, with O C and O B as radii. It is clear that the points C and c, and B and b, being respectively equally distant from the observer, the sounds produced there will be heard simultaneously, and, supposing them equal, will produce the perception of a sound twice as loud as either heard alone would do. All the points on the zigzag c B C b are so placed that three of them are equi-distant from O. Thus, if with O as centre, and O m as radius, a circular arc be described, it will intersect the path of the lightning at three points m, m', and m'', and these three points being, therefore, at the same distance from O, the sounds produced at them will reach the observer at the same moment, and if they be equally intense will produce on the ear the same effect as a single sound three times as loud. The same will be true for all the points of the zigzag between c and b. Thus, in this case, supposing the intensity of the lightning to be uniform from A to D, there will be three degrees of loudness in the sound produced, the least between A and *c* and between *b* and D, the greatest between *c* and *b* along the zigzag, and the intermediate at the points C *c* and B *b*.

It is evident, that from the infinite variety of form and position with relation to the observer, of which the course of the lightning is susceptible, the variations of intensity of the rolling of thunder which may be explained in this way have no limit.

15. Since the loudness of a sound diminishes as the square of the distance of the observer is increased, it is clear that this affords another means of explaining the varying loudness of the rolling of thunder.

16. As the rolling of thunder is much more varied and of longer continuance in mountainous regions than in open plain countries, it is no doubt also affected by reverberation from every surface capable of reflecting sound, which it encounters. A part therefore of the rolling must be in such cases the effect of echo.

It has been also conjectured that the acoustic effects are modified by the effects of interference.

17. A cloud charged with electricity, whatever be the quality of the fluid or the state of the atmosphere around it, exercises by induction an action on all bodies upon the earth's surface immediately under it. It has a tendency to decompose their natural electricity, repelling the fluid of the same name, and attracting to the highest points the fluid of a contrary name. The effects thus actually produced upon objects exposed to such induction, will depend on the intensity and quality of the electricity with which the cloud is charged, its distance, the conductibility of the materials of which the bodies affected consist, their magnitude, position, and, above all, their form.

Water being a much better conductor than earth in any state of aggregation, thunder clouds act with great energy on the sea, lakes, and other large collections of water. The flash has a tendency to pass between the cloud and the water, just as the spark passes between the conductor of an electric machine and the hand presented to it.

18. This explains the fact that lightning sometimes penetrates strata of the solid ground, under which subterranean reservoirs of water are found. The water of such reservoirs is affected by the inductive action of an electrified cloud, and in its turn reacts upon the cloud, as one coating of a Leyden jar reacts upon the other. When this mutual action is sufficiently strong to overcome the resistance of the subjacent atmosphere, and the strata of

soil under which the subterranean reservoir lies, a discharge takes place, and the lightning penetrates the strata, fusing the materials of which it is composed, and leaving a tubular hole with a hard vitrified coating.

Tubes thus formed have been called *fulgurites*, or *thunder tubes*.

19. The well known properties of points, edges, and other projecting parts of conductors, will render easily intelligible the influence of mountains, peaked hills, projecting rocks, trees, lofty edifices, and other objects, natural and artificial, which project upwards from the general surface of the ground. Lightning never strikes the bottom of deep and close valleys. In Switzerland, on the slopes of the Alps and Pyrenees, and in other mountainous countries, multitudes of cultivated valleys are found, the inhabitants of which know by secular tradition that they have nothing to fear from thunder-storms. If, however, the width of the valleys were so great as twenty or thirty times their depth, clouds would occasionally descend upon them in masses sufficiently considerable, and lightning would strike.

Solitary hills, or elevated buildings rising in the centre of an extensive plain, are peculiarly exposed to lightning, since there are no other projecting objects near them to divert its course.

Trees, especially if they stand singly apart from others, are likely to be struck. Being from their nature more or less impregnated with sap, which is a conductor of electricity, they attract the fluid, and are struck.

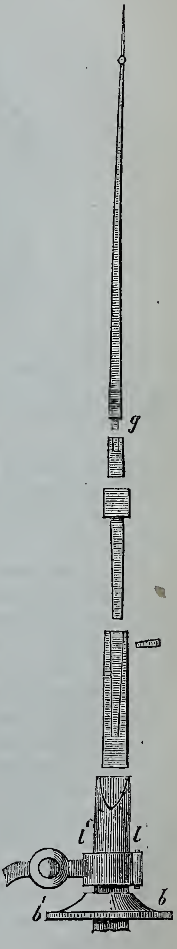
The effects of such objects are, however, sometimes modified by the agency of unseen causes below the surface. The condition of the soil, subsoil, and even the inferior strata, the depth of the roots and their dimensions, also exercise considerable influence on the phenomena, so that in the places where there is the greatest apparent safety there is often the greatest danger. It is, nevertheless, a good general maxim not to take a position in a thunder-storm either under a tree or close to an elevated building, but to keep as much as possible in the open plain.

20. Lightning falling upon buildings chooses by preference the points which are the best conductors. It sometimes strikes and destroys objects which are non-conductors, but this happens generally when such bodies lie in its direct course towards conductors. Thus lightning has been found to penetrate a wall attracted by a mass of metal placed within it.

Metallic roofs, beams, braces, and other parts in buildings, are liable thus to attract lightning. The heated and rarefied air in chimneys acquires conductibility. Hence it happens often that lightning descends chimneys, and thus passes into rooms. It follows bell-wires, metallic mouldings of walls and furniture, and fuses gilding.

21. The purpose of paratonnerres or conductors, erected for the protection of buildings, is not to repel, but rather to attract lightning, and divert it into a course in which it will be innoxious.

Fig. 2.

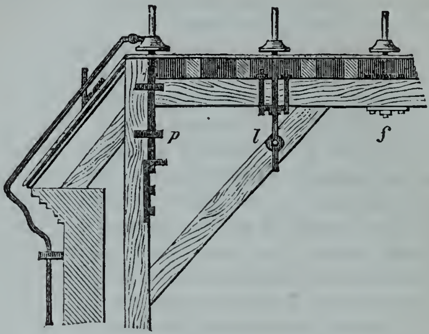


A paratonnerre is a pointed metallic rod, the length of which varies with the building on which it is placed, but which is generally from thirty to forty feet. It is erected vertically over the object it is intended to protect. From its base an unbroken series of metallic bars, soldered or welded together end to end, are continued to the ground, where they are buried in moist soil, or, better still, immersed in water, so as to facilitate the escape of the fluid which descends upon them. If water, or moist soil, cannot be conveniently found, it should be connected with a sheet of metal of considerable superficial magnitude, buried in a pit filled with pounded charcoal, or, better still, with *braise*.

The parts of a well-constructed paratonnerre are represented in fig. 2. The rod, which is of iron, is round at its base, then square, and decreases gradually in thickness to the summit. It is composed commonly of three pieces closely jointed together, and secured by pins passed transversely through them. In the figure are represented only the two extremities of the lowest, and those of the intermediate piece, to avoid giving inconvenient magnitude to the diagram. The superior piece, *g*, is represented complete. It is a rod of brass or copper, about two feet in length, terminating in a platinum point about three inches long, attached to the rod by silver solder, which is further secured by a brass ferule, which gives the projecting appearance in the diagram below the point.

Three of the methods, reputed the most efficient for attaching the paratonnerre to the roof, are represented in fig. 3, at *p*, *l*, and *f*. At *p* the rod is supported against a vertical piece, to which it is attached by stirrups; at *l* it is bolted upon a diagonal brace and at *f* it is simply secured by bolts to a horizontal beam through which it passes. The last is evidently the least solid method of fixing it.

Fig. 3.



The conductor is continued downwards along the wall of the edifice, or in any other convenient course, to the ground, either by bars of iron, round or square, or by a cable of iron or copper wires, such as is sometimes used for the lighter sort of suspension bridges. This is attached, at its upper extremity, to the base of the paratonnerre by a joint, which is hermetically closed, so as to prevent oxidation, which would produce a dangerous solution of continuity.

To comprehend the protective influence of this apparatus, it must be considered that the inductive action of a thunder-cloud decomposes the natural electricity of the rod, more energetically than that of surrounding objects, both on account of the material and the form of the rod. The point becoming surcharged with the fluid of a contrary name from that of the cloud suspended over it, discharges this fluid in a jet towards the cloud, where it combines with and neutralises an equal quantity of the electricity with which the cloud is charged, and, by the continuance of this process, ultimately reduces the cloud to its natural state.

It is therefore more correct to say that the paratonnerre draws electricity from the ground and projects it to the cloud, than that it draws it from the cloud and transmits it to the earth.

It is evidently desirable that all conducting bodies to be protected by the paratonnerre, should be placed in metallic connection with it, since in that case their electricity, decomposed by the inductive action of the clouds, will necessarily escape by the conductor either to the earth or to the cloud by the point.

It is considered generally that the range of protection of a paratonnerre is a circle round its base, whose radius is two or three times its length.

22. The effects of lightning, like those of electricity evolved by artificial means, are threefold, physiological, physical, and mechanical.

When lightning kills, the parts where it has struck bear the marks of severe burning; the bones are often broken and crushed as if they had been subjected to violent mechanical pressure. When it acts on the system by induction only, which is called the secondary or indirect shock, it does not immediately kill, but inflicts nervous shocks so severe as sometimes to leave effects which are incurable.

The physical effects of lightning produced upon conductors is to raise their temperature. This elevation is sometimes so great that they are rendered incandescent, fused, and even burned. This happens occasionally with bell-wires, especially in exposed and unprotected positions, as in courts or gardens. The drops of molten metal produced in such cases set fire to any combustible matter on which they may chance to fall. Wood, straw, and such non-conducting bodies are ignited generally by the lightning drawn through them, by the attraction of other bodies near them which are good conductors.

The mechanical effects of lightning, the physical cause of which has not been satisfactorily explained, are very extraordinary. Enormous masses of metal are torn from their supports, vast blocks of stone are broken, and massive buildings are razed to the ground.

23. No theory or hypothesis which has commanded genera acceptation, has yet been suggested for the explanation of the Aurora Borealis. All the appearances which attend the phenomenon are, however, electrical; and its forms, directions, and positions, though ever varying, always bear a remarkable relation to the magnetic meridians and poles. Whatever, therefore, be its physical cause, it is evident that the theatre of its action is the atmosphere; and that the agent to which the development is due, is electricity, influenced in some unascertained manner by terrestrial magnetism. In the absence of any satisfactory theory for the explanation of the phenomenon, we shall confine ourselves here to a short description of it, derived from the most extensive and exact series of observations which have been made in those regions, where the meteor has been seen with the most marked characters and in the greatest splendour.

24. The Aurora Borealis is a luminous phenomenon which appears in the heavens, and is seen in high latitudes in both

hemispheres. The term Aurora Borealis, or Northern Lights, has been applied to it, because the opportunities of witnessing it are, from the geographical character of the globe, much more frequent in the northern than in the southern hemisphere. The term *aurora polaris* would be a more proper designation.

This phenomenon consists of luminous rays of various colours, issuing from every direction, but converging to the same point, which appear after sunset generally toward the north, occasionally toward the west, and sometimes, but rarely, toward the south. It frequently appears near the horizon, as a vague and diffused light, something like the faint streaks which harbinger the rising sun and form the dawn. Hence the phenomenon has derived its name, which signifies *northern morning.* Sometimes, however, it is presented under the form of a sombre cloud, from which luminous jets issue, which are often variously coloured, and illuminate the entire atmosphere.

The more conspicuous auroras commence to be formed soon after the close of twilight. At first a dark mist or foggy cloud is perceived in the north, and a little more brightness towards the west than in the other parts of the heavens. The mist gradually takes the form of a circular segment, resting at each corner on the horizon. The visible part of the arc soon becomes surrounded with a pale light, which is followed by the formation of one or several luminous arcs. Then come jets and rays of light variously coloured, which issue from the dark part of the segment, the continuity of which is broken by bright emanations, indicating a movement of the mass, which seems agitated by internal shocks, during the formation of these luminous radiations, that issue from it as flames do from a conflagration. When this species of fire has ceased, and the aurora has become extended, a crown is formed at the zenith, to which these rays converge. From this time the phenomenon diminishes in its intensity, exhibiting, nevertheless, from time to time, sometimes on one side of the heavens and sometimes on another, jets of light, a crown, and colours more or less vivid. Finally the motion ceases, the light approaches gradually to the horizon ; and the cloud, quitting the other parts of the firmament, settles in the north. The dark part of the segment becomes luminous, its brightness being greatest near the horizon, and becoming more feeble as the altitude augments, until it loses its light altogether.

The aurora is sometimes composed of two luminous segments, which are concentric, and separated from each other by one dark space, and from the earth by another. Sometimes, though rarely, there is only one dark segment, which is symmetrically pierced round its border by openings, through which light or fire is seen.

25. One of the most recent and exact descriptions of this meteor is the following, supplied by M. Lottin, an officer of the French navy, and a member of the Scientific Commission sent some years ago to the North Seas. Between September, 1838, and April, 1839, this savant observed nearly 150 meteors of this class. They were most frequent from the 17th November to the 25th January, being the interval during which the sun remained constantly below the horizon. During this period there were sixty-four auroras visible, besides many which a clouded sky concealed from the eye, but the presence of which was indicated by the disturbances they produced upon the magnetic needle.

The succession of appearances and changes presented by these meteors are thus described by M. Lottin:—

Between four and eight o'clock, P.M., a light fog, rising to the altitude of six degrees, became coloured on its upper edge, being fringed with the light of the meteor rising behind it. This border becoming gradually more regular, took the form of an arc, of a pale yellow colour, the edges of which were diffuse, the extremities resting on the horizon. This bow swelled slowly upwards, its vertex being constantly on the magnetic meridian. Blackish streaks divided regularly the luminous arc, and resolved it into a system of rays; these rays were alternately extended and contracted; sometimes slowly, sometimes instantaneously; sometimes they would dart out, increasing and diminishing suddenly in splendour. The inferior parts, or the feet of the rays, presented always the most vivid light, and formed an arc more or less regular. The length of these rays was very various, but they all converged to that point of the heavens, indicated by the direction of the southern pole of the dipping needle. Sometimes they were prolonged to the point where their directions intersected, and formed the summit of an enormous dome of light.

The bow then would continue to ascend toward the zenith: it would suffer an undulatory motion in its light—that is to say, that from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from west to east than in the opposite direction. Sometimes, but rarely, a retrograde motion would take place immediately afterward; and as soon as this wave of light had run successively over all the rays of the aurora from west to east, it would return, in the contrary direction, to the point of its departure, producing such an effect that it was impossible to say whether the rays themselves were actually affected by a motion of translation in a direction nearly horizontal, or if this more vivid light was transferred from ray to ray, the system of rays themselves suffering no change of position. The bow, thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a ribbon or flag agitated by the wind. Sometimes one, and sometimes both of its extremities would desert the horizon, and then its folds would become more numerous and marked, the bow would change its character, and assume the form of a long sheet of rays returning into itself, and consisting of several parts forming graceful curves. The brightness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude; these rays would rapidly dart out, and curves would be formed and developed like the folds of a serpent; then the rays would affect various colours, the base would be red, the middle green, and the remainder would preserve its clear yellow hue. Such was the arrangement which the colours always preserved; they were of admirable transparency, the base exhibiting blood-red, and the green of the middle being that of the pale emerald; the brightness would diminish, the colours disappear, and all be extinguished, sometimes suddenly, and sometimes by slow degrees. After this disappearance, fragments of the bow would be reproduced, would continue their upward movement, and approach the zenith; the rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented then the appearance of a large zone of parallel rays, would be estimated; then the vertex of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed. At that moment the rays would be seen in the direction of their feet. If they were coloured, they would appear as a large red band, through which the green tints of their superior parts could be distinguished; and if the wave of light above mentioned passed along them, their feet would form a a long sinuous undulating zone; while, throughout all these changes, the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms.

While these appearances are manifested, new bows are formed, either commencing in the same diffuse manner, or with vivid and ready-formed rays: they succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, having their ends supported on the earth, and, in their arrangement, resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone, traversing the heavens, and disappearing towards the south, becoming rapidly feeble after passing the zenith. But sometimes, also, when this zone extends over the summit of the firmament from east to west, the mass of rays appears suddenly to come from the south, and to form with those from the north the real boreal corona, all the rays of which converge to the zenith. This appearance of a crown, therefore, is doubtless the mere effect of perspective; and an observer, placed at the same instant at a certain distance to the north or to the south, would perceive only an arc.

The total zone, measuring less in the direction north and south than in the direction east and west, since it often leans upon the earth, the corona would be expected to have an elliptical form; but that does not always happen: it has been seen circular, the unequal rays not extending to a greater distance than from eight to twelve degrees from the zenith, while at other times they reach the horizon.

Let it, then, be imagined, that all these vivid rays of light issue forth with splendour, subject to continual and sudden variations in their length and brightness; that these beautiful red and green tints colour them at intervals; that waves of light undulate over them; that currents of light succeed each other; and, in fine, that the vast firmament presents one immense and magnificent dome of light, reposing on the snow-covered base supplied by the ground—which itself serves as a dazzling frame for a sea, calm and black as a pitchy lake—and some idea, though an imperfect one, may be obtained of the splendid spectacle which presents itself to him who witnesses the aurora from the Bay of Alten.

The corona, when it is formed, only lasts for some minutes: it sometimes forms suddenly, without any previous bow. There are rarely more than two on the same night; and many of the auroras are attended with no crown at all.

The corona becomes gradually faint, the whole phenomenon being to the south of the zenith, forming bows gradually paler, and generally disappearing before they reach the southern horizon. All this most commonly takes place in the first half of the night, after which the aurora appears to have lost its intensity: the pencils of rays, the bands, and the fragments of bows appear and disappear at intervals; then the rays become more and more diffused, and ultimately merge into the vague and feeble light which is spread over the heavens, grouped like little clouds, and designated by the name of *auroral plates* (*plaques aurorales*). Their milky light frequently undergoes striking changes in its brightness, like motions of dilatation and contraction, which are propagated reciprocally between the centre and the circumference, like those which are observed in marine animals called Medusæ. The phenomena become gradually more faint, and generally disappear altogether on the appearance of twilight. Sometimes, however, the aurora continues after the commencement of day-break, when the light is so strong that a printed book may be read. It then disappears, sometimes suddenly; but it often happens that, as the daylight augments, the aurora becomes gradually vague and undefined, takes a whitish colour, and is ultimately so mingled with the cirrho-stratus clouds, that it is impossible to distinguish it from them.

Some of the appearances here described are represented in figs. 4, 5, 6, 7, copied from the memoir of M. Lottin.

Fig. 6.

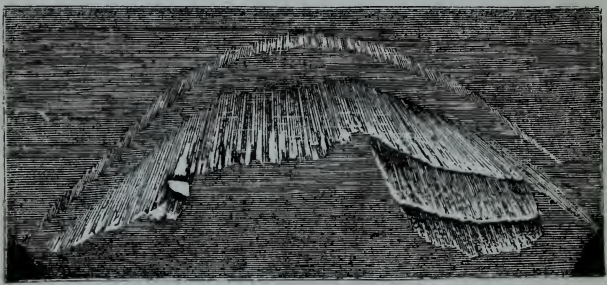
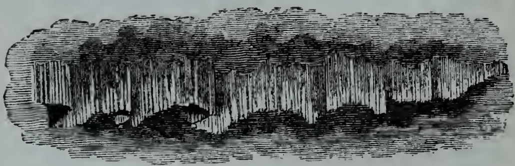


Fig. 7.



The height of the auroras has not certainly been ascertained; but as they are atmospheric phenomena, and scarcely above the region of the clouds, and as they certainly partake of the diurnal motion of the earth, it does not seem probable that their elevation in any case can exceed a few miles.

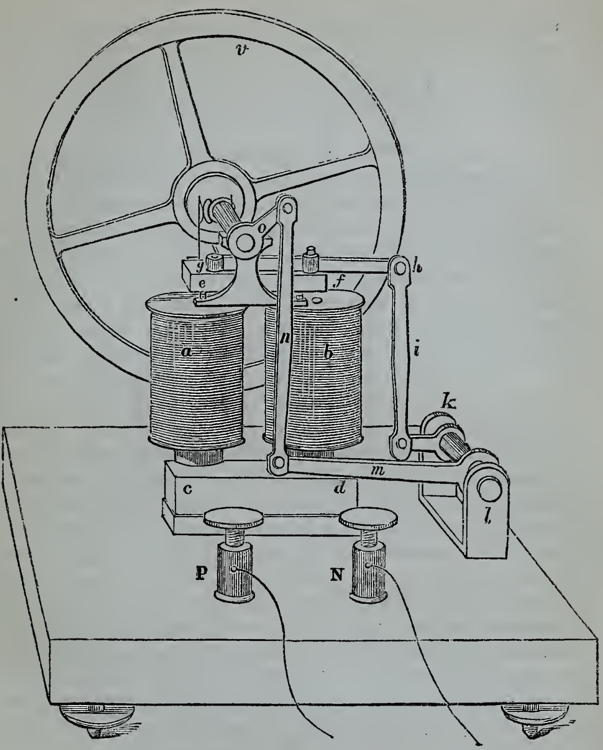


Fig. 2.

ELECTRO-MOTIVE POWER.

CHAPTER I.

1. Prospects of improvement in motive power by the application of electricity.—2. Example of its practical application in the workshop of Mons. Froment, mathematical instrument maker in Paris.—3. Mention of it in Catalogue of the Great Exhibition in Hyde Park. —4. Property of electro-magnets.—5. Alternate transmission and suspension of the current.—6. How this produces a moving power. —7. Voltaic piles used by Mons. Froment.—8. Forms of his electro-

motive machines.—9. Details of their construction.—10. Regulator applied to them.—11. Their application to divide the limbs of philosophical instruments.—12. Their wonderful self-acting power.—13. Application of electro-motive power to the telegraph by Mons. Froment.—14. Microscopic writing.—15. Electric clocks.

1. Among those who have devoted their thoughts to the application of the principles of physical science to the industrial arts, an anticipation more or less sanguine has long been entertained that the day is not far distant when the mighty power of steam, which has exercised, and still continues to exercise, so great an influence upon the well-being of the human race and the progress of civilisation, will be superseded by other far more efficient mechanical agents. Science already directs her finger at sources of inexhaustible power in the phenomena of electricity and magnetism. The alternate decomposition and recomposition of water, by electric action, has too close an analogy to the alternate processes of vaporisation and condensation, not to occur at once to every mind: the development of the gases from solid matter by the operation of the chemical affinities, and their subsequent condensation into the liquid form, has already been essayed as a source of power. In a word, the general state of physical science at the present moment, the vigour, activity, and sagacity with which researches in it are prosecuted in every civilised country, the increasing consideration in which scientific men are held, and the personal honours and rewards which begin to be conferred upon them, all justify the expectation that we are on the eve of mechanical discoveries still greater than any which have yet appeared; that the steam engine itself, with its gigantic powers, will dwindle into insignificance in comparison with the energies of nature which are still to be revealed; and that the day will come when that machine, which is now extending the blessings of civilisation to the most remote skirts of the globe, will cease to have existence except in the page of history.

2. It is not, however, generally known, that there exists in Paris an establishment for the fabrication of philosophical instruments, or rather of that class of those instruments which in that country are distinguished as instruments of precision, in which electro-magnetism is and has been for several years back applied with complete success, as a moving power on a considerable scale.

3. In the Crystal Palace in Hyde Park, a small modest-looking stall furnished with theodolites and some models of electro-magnetic apparatus might have been seen, bearing the inscription of Gustave Froment; and in the Great Illustrated and commentated Catalogue there appeared the three following lines:—

"GUSTAVE FROMENT—5 *rue Ménilmontant, Paris.*

"Scientific Instruments. Theodolite; and various models of electro-motive power."

Assuredly brevity could no further go. Never was presented a more conspicuous example of modest reserve on the part of artistic genius the most exalted. No effort seems to have been thought of by the exhibitor, even to call the attention of the commentators of the catalogue, to the claims of these productions of the highest scientific art; for, while comment and panegyric have been liberally, not to say profusely, accorded to exhibitors, who, whatever may have been their merits, presented claims immeasurably below him whose illustrious labours we are about to notice, not a single word of comment drew the attention of the general public to objects, the fabrication of which would have presented the highest attractions, even to the most idle and incurious of the loungers of the Crystal Palace.

Happily for the cause of science and art, and for that of justice, the same neglect did not prevail among the eminent persons to whom the distribution of honours was entrusted. They discerned and appreciated the titles of M. Froment, and most justly accorded him, by an unanimous vote, a council medal. The authorities of his own country added to this the decoration of the Legion of Honour.

If M. Froment were as ambitious of personal *éclat* as of the attainment of perfection in his workmanship, he would have transported to the Crystal Palace a part of the beautiful machinery of his Parisian workshop, and would have exhibited, not his theodolite alone, but the process of its fabrication. Had he done this (and he might have accomplished it without difficulty), his station in the Great Exhibition as an object of attraction would have rivalled even the Koh-i-noor.

The inventions and improvements of M. Froment, in the construction of instruments of precision, and of scientific apparatus generally, can nowhere be so advantageously seen and appreciated as in his own workshop in Paris. There may be seen not only the finished instruments and machines, but their practical application *in the construction of each other!* There may be seen electro-magnetism applied on a large scale, as a permanent and regular moving power, in the fabrication of mathematical and optical instruments.

The electro-motive machines of M. Froment, which are very various in form, magnitude, and power, derive, nevertheless, their motive force from one common principle, which is the same that has been applied in certain forms of electro-magnetic telegraph.

4. The property of the electro-magnet has been already so fully

explained in our Tract upon the "Electric Telegraph," page 196, that it will be sufficient briefly to recapitulate the general physical principles from which this property arises.

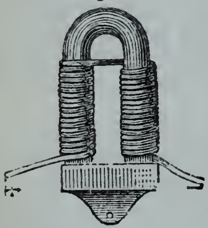
If a voltaic current be conducted spirally round a rod of soft iron, the iron will become magnetic, and will continue magnetic so long as the current passes round it. Its acquisition of the magnetic virtue is simultaneous with the transmission of the current. It is not gradual but instantaneous. The very instant the current is transmitted, the magnetic virtue is imparted to the iron, and does not afterwards increase in intensity.

The loss of the magnetic virtue, upon the suspension of the current, is equally instantaneous and complete. The very instant the current is discontinued, the iron ceases to be magnetic.

The subtlety of the electric fluid, and the celerity of its propagation, are such that it is capable of being transmitted and suspended instantaneously, and, however short the interval may be between the instants of its transmission and suspension, it will, during that interval nevertheless, impart to the iron the magnetic property. So true is this, that it is practically found that the current may be alternately transmitted and suspended hundreds or even thousands of time in a single second, and in these short intervals the iron will alternately acquire and lose the magnetic virtue.

The manner in which the voltaic current is transmitted spirally round the iron bar is as follows:—The wire upon which the current is transmitted is wrapped with silk or cotton thread, which being a non-conductor of electricity, will prevent the lateral escape of the fluid, which will therefore pass along the wire within the coating of thread as water or air would pass along a tube. The wire thus covered is coiled spirally round the bar of soft iron, which may or may not be bent into the horse-shoe form, as shown in fig. 1. One end of the wire being put in connection with the positive, and the other with the negative pole of the voltaic battery; the current will be transmitted upon it, and will be prevented from passing from one coil of the wire to the contiguous one, by the interposition of the silk or cotton thread. So long as the current is thus continued, the iron, whatever be its form, will be magnetic, one end having the properties of the north and the other of the south magnetic pole.

Fig. 1.



5. By an expedient to which an infinite variety of forms may be given, the current can be alternately transmitted and suspended

with any desired degree of rapidity; and, by varying the power of the battery, the number of coils of the spiral wire, and the magnitude of the iron bar, a magnetic force of any desired intensity can be produced.

A piece of iron, called an armature, is presented to one or both of the poles of the magnet towards which it is attracted, while the current is transmitted with a force proportionate to the intensity of the magnetism; and when the current is suspended, the armature either falls from the magnet by its own weight, or is withdrawn from it by the action of a spring, or other mechanical expedient, provided for the purpose.

The armature may be placed between two magnets, which are alternately acted upon by the electric current, which is transmitted round each in the intervals of its suspension round the other. The armature will then be moved alternately to and fro between the two magnets.

6. In this manner, by alternately suspending and transmitting the current on the wire which is coiled round the electro-magnet, the magnet and its armature receive an alternate motion to and from each other, similar to that of the piston of a steam-engine, or the foot of a person who works the treddle of a lathe. This alternate motion is made to produce one of continued rotation by the same mechanical expedients as are used in the application of any other moving power.

The force with which the electro-magnet and its armature attract each other, determines the power of the electro-motive machine, just as the pressure of steam on the piston determines the power of a steam-engine. This force depends on the nature and magnitude of the galvanic pile which is employed.

7. The pile used by M. Froment for the lighter sort of work, such as that of driving his engines for dividing the limbs of astronomical and surveying instruments, and microscopic scales, is that of Daniel, consisting of about twenty-four pairs. Simple arrangements are made by means of commutators, reometers, and reotropes, for modifying the current indefinitely in quantity, intensity, and direction. By merely turning an index or lever in one direction or another, any desired number of pairs may be brought into operation, so that a battery of greater or less intensity may be instantly made to act, subject to the major limit of the number of pairs provided. By another adjustment, the copper elements of two or more pairs, and at the same time their zinc elements, may be thrown into connection, and thus the whole pile, or any portion of it, may be made to act as a single pair, of enlarged surface. By another adjustment, the direction of the current can be reversed at pleasure. Other adjustments, equally

simple and effective, are provided, by which the current can be turned on any particular machine, or directed into any room in which it may be required.

The pile used for heavier work, is a modification of Bunsen's charcoal battery, in which dilute sulphuric acid is used in the porous porcelain cell containing the charcoal, as well as in the cell containing the zinc. By this expedient the noxious fumes of the nitric acid are removed, and although the strength of the battery is diminished, sufficient power remains for the purposes to which it is applied.

8. The forms of electro-motive machines constructed by M. Froment are very various. In some the magnet is fixed, and the armature moveable; in some both are moveable.

In some there is a single magnet and a single armature. The power is in this case intermittent, like that of a single-acting steam-engine, or that of the foot in working the treddle of a lathe, and the continuance of the action is maintained in the same manner by the inertia of a fly-wheel.

In other cases two electro-magnets and two armatures are combined, and the current is so regulated, that it is established on each during the intervals of its suspension on the other. This machine is analogous in its operation to the double-acting steam-engine, the operation of the power being continuous. The force of these machines may be augmented indefinitely, by combining the action of two or more pairs of magnets.

Another variety of the application of this moving principle, presents an analogy to the rotatory steam-engine. Electro-magnets are fixed at equal distances round a wheel, to the circumference of which the armatures are attached at corresponding intervals. In this case the intervals of action and intermission of the currents are so regulated, that the magnets attract the armatures obliquely as the latter approach them, the current, and consequently the attraction, being suspended the moment contact takes place. The effect of this is, that all the magnets exercise forces which tend to turn the wheel on which the armatures are fixed constantly in the same direction, and the force with which it is turned is equal to the sum of the forces of all the electro-magnets which act simultaneously.

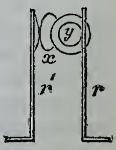
This rotatory electro-motive machine is infinitely varied, not only in its magnitude and proportions, but in its form. Thus in some the axle is horizontal, and the wheel revolves in a vertical plane; in others the axle is vertical, and the wheel revolves in a horizontal plane. In some the electro-magnets are fixed, and the armatures moveable with the wheel; in others both are moveable. In some the axle of the wheel which carries the armatures is itself moveable, being fixed upon a crank or eccentric. In this case the wheel revolves within another, whose diameter exceeds its own by twice the length of the crank, and within this circle it has an hypocycloidal motion.

Each of these varieties of the application of this power, as yet novel in the practical operations of the engineer and manufacturer, possesses peculiar advantages or convenience, which render it more eligible for special purposes.

9. *Electro-motive machines.*—To render this general description of M. Froment's electro-motive machines more clearly understood, we shall add a detailed explanation of two of the most efficient and useful of them.

In the machine represented in fig. 2, *a* and *b* are the two legs of the electro-magnet; *c d* is the transverse piece uniting them, which replaces the bend of the horse-shoe; *e f* is the armature confined by two pins on the summit of the leg *a* (which prevent any lateral deviation), the end *f* being jointed to the lever *g h*, which is connected with a short arm projecting from an axis *k* by the rod *i*. When the current passes round the electro-magnet, the lever *f* is drawn down by the attraction of the leg *b*, and draws with it the lever *g h*, by which *i* and the short lever projecting from the axis *k* are also driven down. Attached to the same axis *k* is a longer arm *m*, which acts by a connecting rod *n* upon a crank *o* and a fly-wheel *v*. When the machine is in motion, the lever *g h* and the armature *f* attached to it recover their position by the momentum of the fly-wheel, after having been attracted downwards. When the current is again established, the armature *f* and the lever *g h* are again attracted downwards, and the same effects ensue. Thus, during each half-revolution of the crank *o*, it is driven by the force of the electro-magnet acting on *f*, and during the other half-revolution it is carried round by the momentum of the fly-wheel. The current is suspended at the moment the crank *o* arrives at the lowest point of its play, and is re-established when it returns to the highest point. The crank is therefore impelled by the force of the magnet in the descending half of its revolution, and by the momentum of the fly-wheel in the ascending half.

Fig. 3.

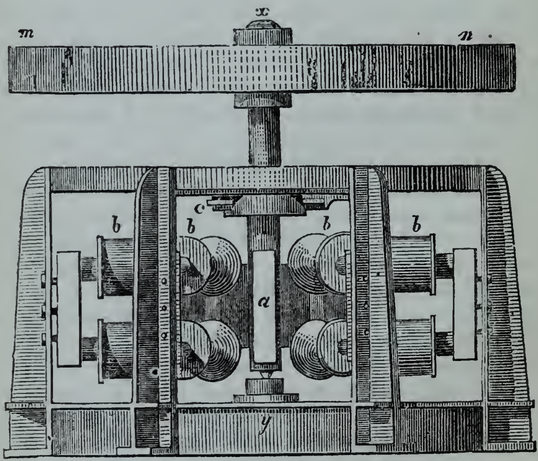


The contrivance called a *distributor*, by which the current is alternately established and suspended at the proper moments, is represented in fig. 3, where *y* represents the transverse section of the axis of the fly-wheel; *r*, a spring which is kept in constant contact with it; *x*, an eccentric fixed on the same axis *y*, and revolving with it and *r'* another spring similar to *r*, which is acted upon by the eccentric, and is thus allowed to press against the axis *y* during half the revolution, and removed from contact with it during the other half-revolution. When the spring *r′* presses on the axis *y* the current is established; and when it is removed from it the current is suspended.

It is evident that the action of this machine upon the lever attached to the axis *k* is exactly similar to that of the foot on the treddle of a lathe or a spinning-wheel; and as in these cases, the impelling force being intermittent, the action is unequal, the velocity being greater during the descending motion of the crank *o* than during its ascending motion. Although the inertia of the fly-wheel diminishes this inequality by absorbing a part of the moving power in the descending motion, and restoring it to the crank in the ascending motion, it cannot altogether efface it.

Another electro-motive machine of M. Froment is represented in elevation in fig. 4, and in plan in fig. 5. This machine has the

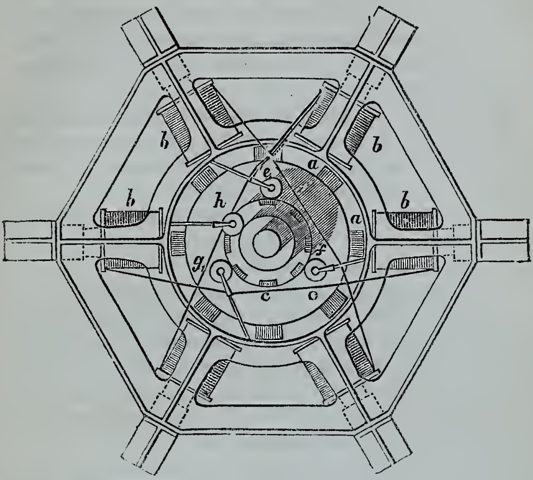
Fig. 4.



advantage of producing a perfectly regular motion of rotation, which it retains for several hours without sensible change.

A drum, which revolves on a vertical axis *x y*, carries on its circumference eight bars of soft iron *a* placed at equal distances asunder. These bars are attracted laterally, and always in the same direction, by the intermitting action of six electro-magnets *b*, mounted in a strong hexagonal frame of cast-iron, within which the drum revolves. The intervals of action and suspension of the current upon these magnets are so regulated that it is established upon each of them at the moment one of the bars of

Fig. 5.



soft iron *a* is approaching it, and it is suspended at the moment the bar begins to depart from it. Thus the attraction accelerates the motion of the drum upon the approach of the piece *a* towards the magnet *b*, and ceases to act when the piece *a* arrives in front of *b*. The action of each of the six impelling forces upon each of the eight bars of soft iron attached to the drum is thus intermitting. During each revolution of the drum, each of the eight bars *a* receives six impulses, and therefore the drum itself receives forty-eight impulses. If we suppose the drum to make one revolution in four seconds, it will therefore receive a succession of impulses at intervals of the twelfth part of a second, which is practically equivalent to a continuous force.

The intervals of intermission of the current are regulated by a simple and ingenious apparatus. A metallic disc *c* is fixed upon the axis of rotation. Its surface consists of sixteen equal divisions, the alternate divisions being coated with non-conducting matter. A metallic roller *h*, which carries the current, presses constantly on the surface of this disc, to which it imparts the current. Three other metallic rollers *e*, *f*, *g* press against the edge of the disc, and, as the disc revolves, come alternately into contact with the conducting and non-conducting divisions of it. When they touch the conducting divisions, the current is transmitted; when they touch the non-conducting divisions, the current is interrupted.

Each of these three rollers *e*, *f*, *g* is connected by a conducting wire with the conducting wires of two electro-magnets diametrically opposed, as is indicated in fig. 5, so that the current is thus alternately established and suspended on the several electro-magnets, as the conducting and non-conducting divisions of the disc pass the rollers *e*, *f*, and *g*.

10. M. Froment has adapted a regulator to this machine, which plays the part of the governor of the steam-engine, moderating the force when the action of the pile becomes too strong, and augmenting it when it becomes too feeble.

A divided circle *m n*, fig. 4, has been annexed to the machine at the suggestion of M. Pouillet, by which various important physical experiments may be performed.

11. Of all the purposes to which this moving power is applied in the workshop of M. Froment, the most beautiful is that of making the divisions on the limbs and scales of astronomical and geodesical instruments, and of instruments of precision in general. The machines by which such divisions are engraved are automatic, each receiving its motion from an electro-motive machine of proportionate power and magnitude.

The limb to be divided is fixed upon a horizontal table, which receives a slow and intermitting progressive motion from a fine screw. This screw itself is urged at intervals by a ratchet-wheel. The catch or click by which this ratchet-wheel is driven, can be so adjusted as to take one, two, or several teeth at each stroke, and therefore to move the table carrying the limb through a greater or less space, according to the magnitude of the divisions to be engraved upon the scale. Over the limb to be engraved is placed the point or edge by which the incision is produced, which is either hardened steel or diamond. During the progressive motion of the table carrying the limb, this cutter is elevated, so as not to touch it. In the intervals during which the motion of the table is suspended, the cutter descends upon the limb, and, being pressed upon it with sufficient force, is drawn upon it in a direction at right angles to the motion of the table, thus engraving upon it the line which marks the division. Thus the motions of the limb and the cutter are alternate, each being in action while the other is at rest. The cutter is fixed upon an arbor which derives its motion from the same crank which works the ratchet, but its connection is arranged so as to give them the alternate action just mentioned.

By an arrangement provided in this arbor, a more extended motion is imparted to the cutter at every tenth stroke of the ratchet, the effect of which is, that every tenth division made upon the limb by the cutter is distinguished by a longer line than the intermediate divisions.

In some cases both the motions above described are imparted to the cutter, the limb upon which the divisions are engraved being kept at rest. The cutter is, in that case, alternately impressed with two motions, one which transfers it from division to division while it is raised from the limb, and the other in a direction at right angles to this, while it is pressed upon the limb, and makes the incision which marks the division.

These dividing instruments vary in form and magnitude according to the purposes to which they are applied.

Those which are used for engraving the divisions on the circular limbs of theodolites and other instruments of the larger class, consist of a circular metallic table of solid construction and suitable magnitude, to which a motion round its centre in its own plane is imparted by means of a finely-constructed worm, which works in teeth formed on the edge of the circular table itself. Means are provided by which the circular limb to be divided can be fixed upon this table, so as to be exactly concentric with it, and to be moved with it. The cutter is fixed so as to slide upon a rod which is extended over this table and parallel to it. The cutter can, by this arrangement, be adjusted at any required distance from the centre of the table, so as to correspond to a circular limb of any magnitude not exceeding that of the table.

In the process of engraving the divisions, the worm and the cutter are moved alternately by self-acting mechanism, deriving its motion from the electro-motive machine by which all the apparatus of the workshop is driven. The worm is so adjusted, that by each action on the table, the limb to be engraved is moved under the cutter (which is then elevated so as not to act upon it), through a space equal to the interval between the divisions. The worm then stops, and the limb being at rest, the cutter descends upon it, and is drawn through a space equal to the length of the line to be engraved, and the division is accordingly marked upon the limb. The cutter is then again elevated, and the limb again moved under it by the worm, and so on.

In this case the divisions which mark degrees are distinguished from the intermediate minutes by larger lines, mechanical arrangements being provided in the wheelwork by which the motion of the cutter is thus affected.

12. All these machines are self-acting. The limb or scale to be divided being once placed on the table of the dividing engine, no further interference of the human hand is needed. The machine of itself begins its work at an appointed hour, minute, and

second, and when the last division of the scale has been engraved, it not only suspends its own action, but stops that of the electro-magnetic machine by which it is impelled. These automatic arrangements must not be regarded as mere mechanical superfluities, upon which the boundless fertility of invention which characterises the genius of M. Froment has been lavished; they are of great practical value and importance. It happens, for example, that in these delicate operations, the tremor of the ground on which the workshop stands, produced by the movement of vehicles of transport in the adjoining streets, affects in a sensible degree the motion of the cutting point. It is therefore always preferable to execute the most delicate work in the dead of the night. Now, by the automatic contrivances above mentioned, this can be accomplished without imposing on the superintendent the necessity of watching. A clock, provided with an apparatus similar in principle to a common alarum, is put in mechanical connection with the dividing machine, and is set so as to start the machine at any desired hour. This being done, and the limb to be divided being fixed upon the table under the cutter, the apparatus may be left to itself; the superintendent may retire to rest, and at the hour of the night which has been selected. the electro-motive machine will be started by the clock, and the dividing engine will commence, continue, and complete its work with the most admirable certainty and precision, and, when completed, the electro-motive machine will be stopped, and all reduced to rest.

The magnitude of the dividing engine for microscopic scales, is about 8 inches long by 6 inches wide, and 4 inches high. The magnitude of the electro-motive engine necessary to drive it, is not more than 4 inches square in its base, and 3 inches high.

It is scarcely necessary to observe, that the more minute class of these scales can only be seen by the aid of a microscope of high magnifying power. This will be easily understood when it is considered that, in a space measuring a tenth of an inch in length, there are in the more minute scales, 2500 divisions. Such is, nevertheless, the precision of the execution, that when looked at with a sufficiently high magnifying power, the lines exhibit the most perfect evenness and regularity.

13. Among the inventions of M. Froment, which may be also seen in operation in his establishment, are two electric telegraphs, one of which transmits its messages by enabling an operator at one station to direct an index, which moves upon a dial-plate, to any desired letter of the alphabet, those letters being engraved around the dial like the hour-mark upon a clock or watch. The

transmitting agent has before him a row of keys, like those of a piano-forte (fig. 6), upon which the letters of the alphabet are

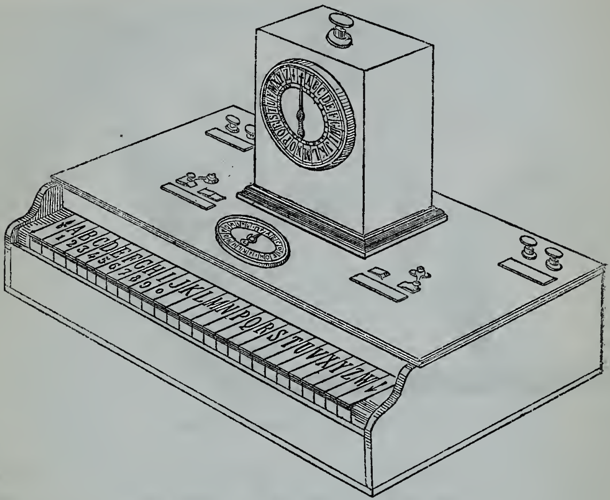


Fig. 6.—Froment's Alphabctical Telegraph.

engraved. When he presses down the key upon which any letter is inscribed, the index of the dial at the distant station with which he is in communication turns, and stops when it points at the same letter. In this way, by indicating the successive letters of the words composing the message, the despatch is transmitted.

The mechanism by which this is accomplished, is fully described in our Tract on the "Electric Telegraph," par. 205.

Another form of electric telegraph (fig. 7), which writes the message it transmits, may also be seen in operation in M. Froment's workshop.

The message is transmitted in this instrument by pressing down a key successively by the finger, the key being held down a longer or shorter time, in the same manner as a pianist would play notes of greater or less length. Varying marks of corresponding lengths are made upon paper by a pencil at the distant station, the paper being moved under the pencil by suitable mechanism. For a description of this telegraph see also our Tract on the "Electric Telegraph," par. 207.

14. Another of the results of the mechanical ingenuity of this artist, which may be seen at his workshop, which if not the most useful is assuredly the most astonishing, and to many the most

incomprehensible, is his microscopic writing, which has been already noticed in our Tract on Microscopic Drawing and

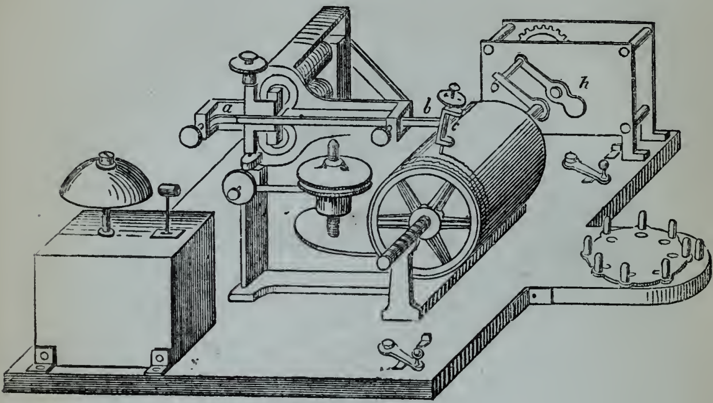


Fig. 7.—Froment's Writing Telegraph.

Engraving. We will here reproduce from that article a specimen of this miraculous performance. Fig. 8, written in the Crystal Palace, in 1851, within a circular space, having the diameter of the 30th of an inch.

The details of the method by which this microscopic writing is executed have not yet been made public, but we believe the inventor is preparing a memoir on the subject, to be presented to the Academy of Sciences.

15. This brief notice of the application of electro-motive power must not be concluded without mentioning its remarkable application to chronometers, examples of which may be seen in many parts of this country, one of which is presented daily and nightly in the Strand, near the Electric Telegraph Office.

The general principle of this beautiful application of physical science to the economy of life is easily explained.

The hand of a clock or watch moves not uniformly, but by a succession of starts, as may be plainly seen in the case of a seconds' hand of a watch or clock. The same intermitting motion affects the minute and hour hands, but their movement from second to second is so minute that it is imperceptible to the eye.

Now, from what has been already explained, it will be evident that a similar intermitting motion can be imparted to the contact piece of an electro-magnet by the alternate transmission and suspension of the current. If, therefore, by any means the electric current can be transmitted and suspended alternately with chronometric regularity, so that, for example, the interval of its

Fig. 8.—Appearance as seen in the field of the Microscope the outer circle being only 1-30th of an inch in diameter.

transmission and suspension shall be exactly one second of time, then the motion to and fro of the contact piece will also be performed with the same chronometric regularity, in intervals of one second. It is evident, therefore, that if such a contact piece, so moving, be put in connection with a properly constructed frame of wheel-work, it may be used to impart motion to the hands of a timepiece.

It appears also that the same regularly intermitting current may be transmitted to any number of timepieces, at any distance whatever from each other, by means of conducting wires similar to those of the electric telegraph; and since the length of such intermediate wires does not affect their power of transmission, it follows that the same current can simultaneously impart a perfectly regular chronometric motion, to all the clocks dispersed over a large country.

It remains only to show how the regularity of the intermission of the current can be obtained. This is accomplished by the obvious expedient of putting the commutator, by the motion of which the current is alternately transmitted and interrupted, in connection with a well-regulated chronometer, the pendulum of which shall, in that case, itself alternately transmit and suspend the current.

Among the numerous applications of electric power to be seen in the workshops of M. Froment, are a series of electric clocks constructed nearly upon the principle above described. The motion of each clock is in this case maintained by a small weight, which is alternately raised and lowered upon an appendage of the pendulum by means of an iron counterweight, which is itself alternately raised and disengaged by an electro-magnet, each time that the appendage, by its contact with the weight, opens and closes the voltaic circuit, or, what is the same, transmits and suspends the current.

The motion of the clock is maintained by a constant weight, without friction and without the application of oil, with great regularity, while the electric current, which is transmitted through it in the intervals of each oscillation, transmits to a distance the chronological indications upon a series of dials, the hands of which are moved by a mechanism, analogous to that which moves the index of an electric telegraph of the kind used on the continental railways.

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